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Research Article

Monitoring Water Quality: Suggestions and Prospects

[1]Abdul Aziz Muhammad Sani*, [2]Muhammad Kabir Sani, [3]Muhammad Auwal Umar, [4] Kamal Kabiru Ado, [3]Abdulkadir Shehu Bari, [5]Muhammad Ahmad Baballe.
[1]Department of Chemical Engineering, Bayero University Kano, Nigeria.
[2] Department of Petroleum Engineering, Bayero University Kano, Nigeria.
[3] Department of Computer Science, Audu Bako College of Agriculture Dambatta, Kano, Nigeria.
[4] Department of Computer Science, Federal College of Agricultural Produce Technology (FCAPT), Kano, Nigeria.
[5] Department of Mechatronics Engineering, Nigerian Defence Academy (NDA), Kaduna, Nigeria.

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Corresponding author: ***Abdul Aziz Muhammad Sani***
Department of Chemical Engineering, Bayero University Kano, Nigeria.

Abstract

Water quality is one of the most important variables affecting human life. Usually, it is necessary to evaluate the water's quality right away. If the area to be investigated is large, testing at several places will be necessary. Repeatedly evaluating the water quality will be challenging and time-consuming. A real-time monitoring system is required to protect the water and check its condition to prevent contamination. The water quality is tracked and shown using environmental sensors. LoRa technology (Long Range) refers to a group of wide-area communication technologies with enhanced obstacle occlusion, longer signal propagation distances, and the Node-RED application. It entails monitoring and collecting information on variables including air pollution, turbidity, pH, electrical conductivity, and climate that have an impact on water quality. The study's microcontroller processes the sensor data before wirelessly sending it to the database structure, where it is shown on the Node-RED display. A Node-RED dashboard and real-time water quality monitoring are features of the IoT-based monitoring system. Future directions will concentrate on satellite technology, machine learning for emerging contaminants (like microplastics), and integrated watershed management. Water quality monitoring is moving toward real-time, data-driven approaches using IoT, AI, and smart sensors, enabling faster response to pollution. However, this requires better integration of chemical and biological data, stakeholder involvement, and standardized protocols for diverse contaminants.

Keywords: *Future Directions, Recommendations, Challenges, Water quality, Internet of things (IoT), LoRa technology.*

I. INTRODUCTION

An essential natural resource for human consumption is water. The amount of water on Earth is roughly 326 million trillion gallons. Less than 3% of the world's water supply is freshwater, and more than two-thirds of that amount is frozen in icebergs and glacier crowns. Even though it is a plentiful natural resource, only 0.04% of it may be utilized [1, 2]. The two main categories of freshwater sources are surface water sources, such as rivers, canals, waterfalls, dams, and reservoirs, and groundwater sources. In addition, due to waste generation and chemical leaks, industrial and agricultural operations are expanding quickly and have a substantial impact on environmental contaminants. Making sure that water resources are safe and usable is essential. The world is experiencing issues with water demand and contamination as a result of growing globalization. To prevent any quality issues brought on by water intake from diverse activities, water quality must be paid close attention. Three categories can be made for water quality parameters. The first group includes physical characteristics like electrical conductivity, turbidity, chromaticity, warmth, smell, and color. The second group of chemical properties includes elements like pH, dissolved oxygen, chemical oxygen demand (COD), biochemical oxygen demand (BOD), complete inorganic carbon, heavy metal ions, and nonmetallic toxins. All bacteria and coliforms fall within the microbiological category, which is the third category [3]. Water samples must be manually collected from various locations in order to be tested for quality, which is a tedious and time-consuming process. Researchers are therefore interested in evaluating water quality utilizing Internet of Things (IoT) technology, which is a novel strategy nowadays. The term "IoT" describes network-connected devices as well as, more recently, the value chain that results from the connection of things, data, people, and services. The sensors on these, along with other IoT gadgets, have to be linked to the network because they are all accumulator powered. The IoT currently significantly contributes to data monitoring, recording, storing, and displaying in addition to communication. IoT systems open up new possibilities for finding economical resources [4]. Recent years have seen an increase in the application of IoT technology to solve environmental problems such as air quality, water pollution, and radiation contamination [5-7]. Recent studies indicate that they have made use of IoT technology to enable real-time monitoring in order to streamline operations and regulate water quality more effectively. LoRa and LPWAN technologies are frequently utilized in IoT systems because of their flexible and reliable technical attributes, along with their capacity to attain extended communication distances with minimal power consumption, cost-effectiveness, and high data transfer speeds in system deployment [8-11]. However, zoning or national considerations are necessary for the deployment of LoRa technology. This is due to the necessity that LoRa devices be used at the designated frequencies in each nation [12]. Finally, users must comprehend LoRa technology's operation in order to apply roller technology. This is a useful manual for selecting the appropriate equipment. Consequently, the main objective of this study was to develop and assess the performance of a water quality monitoring system that was mounted on a robot (boat) for community usage and used IoT detectors to determine parameters related to water quality like temperatures, the conductivity of electricity, pH, air purity, and turbidity with LoRa wireless communication. Information on water quality was also shown using Node-RED technology.

II. RECOMMENDATIONS FOR CURRENT MONITORING

i. **Integrate Data Streams:** Combine chemical (contaminants, pH, DO) with biological (bioindicators) data for a holistic impact assessment, not just exposure.
ii. **Standardize Protocols:** Develop clear QA/QC procedures and protocols for diverse contaminants and ecological assessments.
iii. **Enhance Spatial/Temporal Resolution:** Use high-density sensor networks to capture water quality's spatiotemporal variability, balancing coverage with frequency.
iv. **Engage Stakeholders:** Involve local knowledge and communities through Participatory GIS for effective watershed management.

III. FUTURE DIRECTIONS & EMERGING TECHNOLOGIES

i. **IoT & Smart Sensors:** Deploy networks of IoT sensors for continuous, real-time monitoring of pH, DO, turbidity, temperature, and chemical presence, enabling rapid alerts.
ii. **Artificial Intelligence & Machine Learning (AI/ML):** Use AI/ML with spectral data for rapid detection and fingerprinting of emerging contaminants (microplastics, pesticides) and predicting contamination events.
iii. **Satellite Remote Sensing:** Employ satellites and machine learning to monitor contaminants (like dissolved organic matter optical signatures) across river-to-ocean systems.
iv. **Modular Sensor Systems:** Utilize flexible, modular loggers (like the MX800 series) that can combine data from multiple sensors (CTD, DO) for calculating complex parameters like salinity-adjusted DO.
v. **Intelligent Decision Support:** Develop AI-driven systems to help watershed managers interpret complex data and optimize monitoring networks.
vi. **Water 4.0 Technologies:** Adopt advanced tools (IoT, Big Data) through phased rollouts, public-private partnerships, and diverse funding for smart water governance.

IV. KEY FOCUS AREAS FOR THE FUTURE

i. **Emerging Contaminants:** Improve detection and monitoring of persistent pollutants (pharmaceuticals, microplastics).
ii. **Cause-Effect Linkages:** Better link contaminant occurrence with adverse biological effects.
iii. **Sustainable Implementation:** Develop cost-effective, scalable strategies for smart monitoring, including public-private collaborations.
iv. **SDG 6 Alignment:** Use monitoring to track progress on the Sustainable Development Goal 6 (Clean Water and Sanitation) [36].

V. METHODOLOGY

Physical elements, technical network setup and configuration, operational protocols, and data formats make up the IoT architecture, which is a framework. IoT architecture implementation may look very diverse. Open protocols must therefore be adaptable enough to handle a wide range of network applications. The three-layer design is the most typical and widely accepted structure. It was utilized in the early stages of this IoT investigation. Perception, network, and application are the three layers that are mentioned [13]. A microcontroller board at the perception layer connects sensors to the network layer. In this investigation, the researchers built a sensor monitoring system utilizing a microcontroller board that gathers information on the temperature, conductivity, pH, turbidity, and quality of the air before transmitting it using LoRa technology. The LoRa technology enables device-to-device communication. The microcontroller board receives the data and processes it [14]. The Node-RED application, which users can access from their laptops, displays all of the sensor readings. The term "LoRa" (Long Range) refers to a group of wide-area communication technologies that have better obstacle occlusion and longer signal propagation distances. It can be used for transmission-related purposes and operates without a license in the radio frequency bands at a frequency below 1 GHz (920-925 MHz in Thailand). When employed in difficult settings, LoRa can enable long-range broadcasts of more than 10 km in open-area testing. Transmission is limited to a radius of less than 1 km. The Doppler effect, which impacts signal reception, and comparable speeds were taken into consideration in the study's analysis of LoRa performance [15]. It concluded that, depending on the hardware configuration selected, the communication might not function. It also carried out coverage of both land and water. Two types of LoRa technology are in use: LoRa and Lora WAN. In this instance, Lora will be utilized without authorization in a frequency range. Point-to-point communication will be the main focus between each LoRa active node. The service area is limited, but LoRaWAN enables interaction between LoRa nodes and remote end nodes through LoRa gateways, enabling the network to offer long-distance communications comparable to those of a WAN network [3, 16]. Media access control protocol (MAC), the top layer of the physical layer, is used by the LoRaWAN for communication. The three most frequently used frequency bands are 433 MHz in North America, 868 MHz in Europe, and 915 MHz in North America [17, 19]. The fundamental idea behind this study is the use of sensors to gauge water quality metrics and the wireless transmission of that data using LoRa technology. There are two components to it: a transmitter and a receiver. The transmitter is made up of sensors that gather information about water quality metrics from water sources and a TTGO LoRa32 development board. The TTGO LoRa32's LoRa communication feature is used to transmit the collected data to the receiver, who then receives the water quality data and presents it on a Node-RED application. To track environmental variables, an IoT sensor network is integrated by a microcontroller called the TTGO T-Beam ESP32. The ESP32 microcontroller enables GPS connectivity and uses LoRa modules to operate in the 868/915 MHz band. Before providing the sensor data to the application layer, this component will be in charge of sending, receiving, and processing the data. With a temperature accuracy of 0.5°C, the temperature detector (DS18B20 Arduino) measures the water's temperature in degrees Celsius (°C). With an accuracy of -10 to 85°C, the operative temperature range is -55 to 125°C [20]. A thermometer was used to calibrate the temperature sensor at various temperatures. According to the test findings, the temperature sensor's accuracy was 94.05%. When determining whether a given supply of water is suitable for human consumption and use, water temperature is vital. For many aquatic creatures, it also has an impact on oxygen. The World Health Organization (WHO) advises keeping the water between 20 and 30°C [21]. A tool for determining a liquid's electrical conductivity, or the total dissolved solids (TDS) in water, is a total dissolved solids (TDS) sensor. Micro-Siemens per centimeter of water (S/cm) units are used to express how well water conducts electricity when there are dissolved inorganic substances. Effects of water conductivity on aquatic species' capacity for survival and reproduction Conflict and other negative outcomes may emerge from high conductivity values [22]. Maintaining the quality of the water requires regular analysis of electrical conductivity. The TDS sensor utilized in this study has a measuring range of 0-1000 ppm and an accuracy of 10% of the overall scale, making it suitable for experimenting. The pH sensor, also known as an analog pH meter, is a device that assesses the acidity and alkalinity of water as well as the pH of any solution. Numerous applications, such as aquaponics, aquaculture, and environmental water testing, make extensive use of it. According to the negative logarithm of the hydrogen-ion concentration, the pH sensor is often built to produce a value between 0 and 14 as needed. pH is defined as pH = -log [H+]. The pH range for intake in this case should be between 6.0 and 8.5, which is within the typical pH range for human existence [4, 23]. The pH sensor in this investigation was calibrated using a pH meter. The Mettler Toledo S210 is what it is. The pH calibration powder is used to calibrate the accuracy of the electronic pH measurement probe. According to the test results, the pH sensor has a 96.95% accuracy rate. The turbidity sensor is utilized to gauge the water's level of turbidity. It looks at the transmittance and scattering rate of the light to locate suspended particles in water. Depending on the total suspended solids' quality, this rate varies. (TSS). The range of 0.1-1000 Nephelometric Turbidity Units is considered to be the most typical range of water turbidity measurements. (NTU). Turbidity in river water might reach 150 NTU [24, 25]. The sensor used in this study measures the light that is refracted in water and converts it to an analog output turbidity value of 0-4.5 volts with a 500 ms measurement accuracy. Volts were used to compare turbidity to 0-1000 NTU. Standard values were used to calibrate the turbidity sensor. The instrument's accuracy was discovered to be 91.03%. An air quality sensor from the MQ series, the MQ-135 gas sensor can measure and detect a wide range of gases, including smoke, nitrogen oxides, ammonia, carbon dioxide, benzene, and alcohol. When it absorbs these gases, the sensor's resistance changes, which is how it works. Its primary job is to track the air quality by looking for these gases. A tin oxide sensing layer, a heating coil, and a ceramic tube made of aluminum oxide, Al_2O_3, make up the sensor. The analog TTL requires 5 volts to operate, making it compatible with the majority of microcontrollers [26]. Application programming interfaces (APIs), hardware components, and internet services can all be integrated with Node-RED. It enables more flexible working for developers by allowing them to connect devices to APIs through a configurable web browser. It is advised to install Node-RED on personal PCs to maintain the platform's security and privacy. The graphical user interface of this application makes it very well-liked [27-30]. Additionally, it is a potent tool for creating visual programming-based IoT applications. The current study makes use of the Node-RED dashboard library to implement gauges, charts, serial connections, functions, and switches and use them to display data from sensor information. To monitor the quality of water resources, a wireless electric boat-based prototype of a mobile water quality collector has been created. The dimensions of the fuel cell employed in this study are 280 mm in width, 175 mm in height, and 880 mm in length. With the aid of LoRa technology and a TTGO T-Beam ESP32 microcontroller, the mobile collector has every sensor required to measure the water quality. By using LoRa to transmit meter reading instructions and data, the mobile collector is used to keep an eye on water meters and gauge the condition of the equipment. The authors have developed an SWQM system that is based on the IoT and allows for better water quality measurement. The temperature, conductivity, pH, turbidity, and air quality are the five components of water quality.

VI. RESULTS AND DIALOGUE

In this work, the author uses IoT technology to track various water quality indicators, including temperature, turbidity, electric conductivity, pH, and air quality. The apparatus includes a TTGO T-Beam controller, the DS18B20 temperature sensor, the TDS conductivity sensor, the turbidity sensor, the pH meter, and the MQ-135 gas sensor as an air quality sensor [31-33]. transferring data through LoRa and displaying the Node-RED dashboard on a computer to get beyond the limitations of conventional water quality monitoring systems, data on water quality is shown on the Node-RED dashboard once every second for each of those several parameters. For real-time monitoring, this data may also be automatically sent to the Node-RED dashboard [30].

VII. THE GOAL AND BENEFITS OF WATER QUALITY MONITORING

1. Finding specific contaminants, a particular chemical, and the source of the pollution is made easier with the aid of water quality monitoring.
   Among the many causes of water pollution are industrial activity, dumping in rivers and on the ocean floor, the application of pesticides and fertilizers in agriculture, oil pollution, port activity, shipping, and oil spills. Additionally, agricultural operations and sewage effluent are sources. Regular water quality assessments and monitoring serve as a source of information for locating current problems and their causes.
2. Recognizing both short- and long-term water quality patterns.
   Trends can be seen in data obtained over time, such as rising nitrogen pollution levels in a river or other inland waterways. After that, utilizing the whole data, key water quality parameters will be found.
3. Managing and preventing water contamination as part of environmental planning.
   Data gathering, interpretation, and utilization are essential for developing a good and effective water quality strategy. Lack of real time data, however, will make it difficult to create plans and would limit your ability to impact pollution control. The answer to this problem is to use digital systems and tools for data collecting and administration.
4. Compliance with international standards.
   Water quality monitoring is a global issue that affects both land and marine. The European Green Deal outlines goals for restoring biological diversity and reducing water pollution inside the European Union (EU) and publishes numerous regulations to set standards for water quality. Furthermore, each nation state, like France, has its own legal systems that need accurate water quality monitoring. In the US, the Environmental Protection Agency (EPA) is responsible for enforcing state-by-state water contamination laws. The importance of effective water quality monitoring measures and methods is being recognized by nations all over the world.
5. In emergencies, water quality monitoring is a necessity. Instances consist of notable occurrences of oil spills caused by tanker accidents or instances of flooding due to excessive runoff of rainwater. When an emergency arises, quick response is essential, necessitating access to real-time data to determine how pollution levels affect water quality [27].

VIII. CHALLENGES OF MONITORING WATER QUALITY

Inadequate funds and resources, a lack of agency cooperation, challenges with data administration and analysis, and the limitations of present technology to detect developing contaminants are some of the challenges associated with water quality monitoring. Other issues include the need for more community involvement, inadequately trained staff, and inefficient enforcement of current restrictions.

Resource and capacity challenges

i. **Funding and resources:** Many monitoring programs are underfunded, limiting the ability to purchase necessary equipment, establish infrastructure, and conduct regular testing.
ii. **Human capacity:** There is often a shortage of adequately trained personnel, and issues like low staff motivation and high turnover rates can hinder effective monitoring.
iii. **Infrastructure:** A lack of sufficient monitoring stations, equipment, and data management systems is a major obstacle.

Data and technology challenges

i. **Data management:** large datasets are difficult to manage and analyze, especially when there is a lack of interoperability between different systems and no standardized protocols.

ii. **Technological limitations:** Existing methods can be slow and lab-intensive. While new sensor technologies are promising, they may have issues like sensor fouling or limited detection capabilities for emerging pollutants.
iii. **Limited real-time data:** There are significant limitations in real-time monitoring, particularly for groundwater and large surface water bodies, which makes it hard to respond quickly to issues.

Coordination and enforcement challenges

i. **Lack of coordination:** A lack of integration and coordination between different monitoring agencies leads to duplication of efforts and inconsistent data interpretation.
ii. **Weak enforcement:** Policies and guidelines are often not effectively implemented or enforced, and polluters may face no consequences.
iii. **Poor data sharing:** Ineffective data sharing between agencies hinders comprehensive water quality management.

Community and regulatory challenges

i. **Community engagement:** Without public support and understanding, monitoring programs can face difficulties in implementation and securing funding.
ii. **Evolving regulations:** Monitoring methods must be continuously adapted to comply with new and evolving environmental regulations and to address newly identified contaminants [34].

IX. CONCLUSION

The study's goals were to use the Node-RED program for component architecture and design in order to construct, assess, and deploy an IoT- and LoRa-based water quality monitoring system. Temperatures, electrical conductivity, pH, air quality, sediment, and other characteristics of water quality must be measured and recorded, depending on the location that needs to be inspected. The TTGO LoRa32 microcontroller processes the sensor data before sending it via the wireless network to the database and displaying it on the Node-RED dashboard. The results of the investigation demonstrated how data may be sent and received across a distance operation of 2.0 km in locations where LoRa technology is not feasible using a signal transmission that carried over 95.50% of our 600 data sets over this reduced distance. Therefore, over longer distances, less storage will be required. The IoT-based monitoring system may also measure water quality in real time and offer a Node-RED dashboard. Usability testing was shown to be more useful and efficient. This approach is compatible with innovative approaches such as smart cities. Consequently, the need for a real-time monitoring system will grow. Future work will focus on creating a new LoRa antenna to improve signal transmission and incorporating the BOD/COD sensor into the system [35,37].

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