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Water Quality Monitoring System

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Abstract: *Water is perhaps the most precious natural resource after air. Though the surface of the earth is mostly consists of water, only a small part of it is usable, which makes this resource very limited. This precious and limited resource, therefore, must be used with prudence. As water is required for different purposes, the suitability of it must be checked before use. Also, sources of water must be monitored regularly to determine whether they are in sound health or not. Poor condition of water bodies is not only the indictor of environmental degradation, it is also a threat to the ecosystem. In industries, improper quality of water may cause hazards and severe economic loss. Thus, the quality of water is very important in both environmental and economic aspects. Thus, water quality analysis is essential for using it in any purpose. After years of research, water quality analysis is now consists of some standard protocols. There are guidelines for sampling, preservation and analysis of the samples. Here the standard chain of action is discussed briefly so that it may be useful to the analysts and researchers.*

1. INTRODUCTION

Water is a fundamental necessity for all forms of life on Earth. However, due to rapid industrialization, urbanization, and environmental degradation, water sources are becoming increasingly polluted. Contaminated water can cause severe health issues, affecting millions of people worldwide. As such, the need for continuous and accurate water quality monitoring has never been more crucial. Traditionally, water quality analysis has been performed manually in laboratories, which is time-consuming, expensive, and often not feasible for real-time or large-scale applications. Moreover, periodic sampling may miss critical changes in water quality, leading to delayed responses and potential health risks. In light of this, there is an urgent demand for intelligent, real-time, and remote monitoring systems that can continuously analyze water parameters and alert concerned authorities or users immediately when the water becomes unsafe. The development of the Internet of Things (IoT) has opened up new possibilities in environmental monitoring. With advancements in microcontrollers, sensors, and wireless communication, it is now possible to build compact, affordable, and reliable systems that can monitor environmental parameters remotely. One of the key components enabling this transformation is the ESP8266 microcontroller — a low-cost Wi-Fi-enabled device that is well-suited for IoT applications. This project proposes an IoT-based Water Quality Monitoring System using the ESP8266 microcontroller, integrated with multiple sensors to measure the most critical water quality parameters: pH, Turbidity, Total Dissolved Solids (TDS), and Temperature. These parameters provide a comprehensive assessment of the water's chemical and physical properties and help determine its suitability for consumption and usage. The ESP8266 acts as the brain of the system. It reads data from the sensors, processes it, and sends it to a cloud platform — ThingSpeak — over Wi-Fi. ThingSpeak allows users to visualize and analyze real-time data through interactive graphs and dashboards. This data can be accessed from anywhere using a mobile phone or computer, enabling remote monitoring without the need for physical presence. An additional feature of the system is the integration of a GSM module, which is used to send SMS alerts when water quality goes beyond safe thresholds. This ensures that users are immediately notified of potential risks, even in areas with poor or no internet connectivity. To make the system sustainable and deployable in off-grid or rural areas, it is powered using a solar panel with a rechargeable battery. This makes it ideal for continuous, long term monitoring in locations where traditional power sources are unavailable or unreliable. The implementation process involved selecting and calibrating suitable sensors, designing and programming the ESP8266 in the Arduino IDE using C language, setting up ThingSpeak channels for data visualization, and configuring the GSM module for SMS alerts. The system was assembled on a prototype board, tested in different water samples, and evaluated based on accuracy, responsiveness, power efficiency, and reliability. The results of the project demonstrated that the system could accurately monitor water quality in real-time, transmit data wirelessly, and alert users during hazardous conditions. The solution is cost-effective, energy-efficient, and easy to maintain, making it an excellent option for schools, households, farms, water treatment plants, and government agencies concerned with water safety. This project not only addresses the growing need for real-time water quality monitoring but also showcases how embedded systems, cloud computing, and renewable energy can work together to solve real-world environmental problems. The use of ESP8266 significantly reduced the overall cost and complexity of the system, while still maintaining high performance and flexibility. In conclusion, the Water Quality Monitoring System using ESP8266 and IoT provides a scalable and impactful solution for ensuring safe and clean water in both urban and rural settings. By enabling early detection of contamination, the system helps prevent health hazards and supports better decision-making for water resource management.

2. LITERATURE SURVEY

The reported work is based on temperature monitoring of water by using mobile so that cycle offish production and growth can be monitored along with the measurements of temperature ranges from normal to maximum value with the help of controller in real time. The literature recorded focused on sea water and sensors are used to measure temperature, ORP and conductivity. The hardware is based onATmega1281 and frequency of 8 MHz used for implementation. The other work used LPC1768 ARMMCU with GPS to monitor water in rivers and lakes. The additional parameters are carbon monoxide, and humidity. Similar sort of work on lakes and rivers performed by using LPC2148 along with ESP8266Wi-Fi data for transmission and reception and LCD as hardware to display data. The Arduino board is embedded with sensors like temperature, pH and DO (dissolved oxygen) for analyzing water. All the above reported work is based on monitoring of water quality. In other approach the reconfiguration concept is used with help of FPGA board to scan the turbidity, temperature, carbon dioxide by using BEE MCU and Zigbee, GSM hardware for transmission of data. In advancement of quality monitoring of water, the security feature is introduced by. In the recorded work interfacing done through Arduino board and sensors based on wireless sensor network (WSN) with Wi-Fi module. In inaugurate the system that assist the farmers for quality water and Shrimp cultivation at Taipa using IOT. The main equipment used Atmega2560, with Raspberry pi 3 based MQTT. For communication LoRa wireless interface is used. Sensors embedded in system monitoring are temperature, pH, salinity. The work based advance techniques machine learning, deep learning with integration of Big data proposed. The work is based on monitoring of physical parameters like turbidity, pH, temperature, salinity and total dissolved solids (TDS). The work is carried with Arduino board based on ATmega2560 microcontroller and WSN. FPGA based similar approached introduced along with Zigbee protocol for communication and both features water monitoring (temperature, turbidity and pH) and water quantity as well. In this paper [16] author used the Arduino MCU for implementation of water quality monitoring using Wi-Fi and GSM. The chemical and physical parameters incorporate for research are temperature, pH level, electric conductivity. Whereas the reported work in add the water quality with Iot and wireless sensor network (WSN) platform which is for smart city, still scope of controlling the water quantity. There is advancement in communication of the monitored data remotely with the use of IoT. The water quality measurement is tested on two parameters and controlling the water utilization is not done. The recent work reported IoT based using web server for Gouramy cultivation for water quality only.

Block Diagram and its Description:

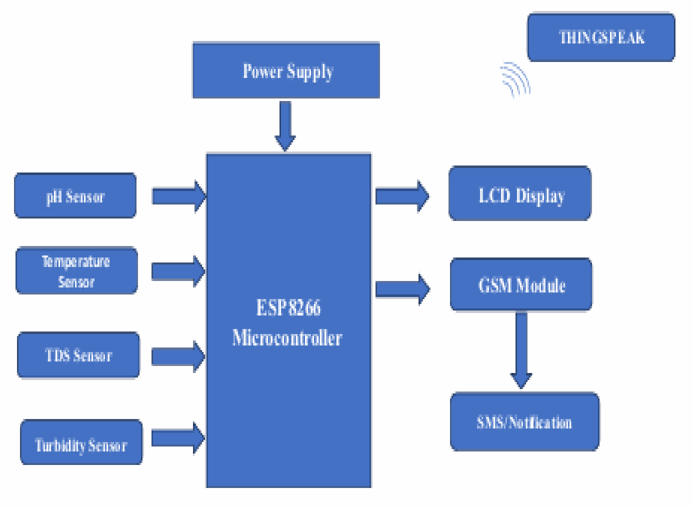

FIGURE 1. Block Diagram of Water Quality Monitoring System

The architecture of the proposed Water Quality Monitoring System is designed around the ESP8266 microcontroller, which acts as the central processing unit responsible for data acquisition, processing, transmission, and alerting. The system is supported by multiple sensors that measure essential water quality parameters, including pH, temperature, TDS (Total Dissolved Solids), and turbidity. Each component is interconnected to ensure efficient and real-time monitoring. Power Supply A regulated power supply system ensures that all hardware components receive adequate and stable voltage for continuous operation. In a practical deployment scenario, the system can be powered using a solar panel with rechargeable batteries, making it suitable for remote and off-grid environments. Sensor Unit The system employs four main sensors. pH Sensor: Monitors the acidity or alkalinity of the water, an important factor in determining water quality. • Temperature Sensor (DS18B20): Detects the current temperature of the water, which influences biological activity and chemical reactions. • TDS Sensor: Measures the concentration of dissolved solids, indicating the purity or contamination level of water. • Turbidity Sensor: Detects suspended particles in water, giving an indication of clarity and contamination. These sensors are interfaced with the ESP8266 microcontroller, which periodically reads data from them through its analog and digital input pins. ESP8266 Microcontroller The ESP8266 is a low-cost Wi-Fi-enabled microcontroller, well-suited for IoT applications. It serves as the core of the system, managing: • Sensor data acquisition and filtering. • Wireless communication with cloud platforms (ThingSpeak). • Displaying real-time data on an LCD screen. • Sending SMS alerts via a GSM module. Its in-built Wi-Fi module allows it to connect to the internet without additional hardware, making it ideal for cloud-based applications. Data Transmission and Visualization The processed sensor data is transmitted to the ThingSpeak cloud platform via Wi-Fi. This platform provides real-time visualization in the form of interactive graphs and dashboards. Users can access this information from any internet-enabled device, including mobile phones. Notification System For critical alerts, the system includes a GSM module. When water quality parameters exceed predefined thresholds, the ESP8266 triggers the GSM module to send SMS notifications to registered users. This ensures immediate awareness of potentially hazardous water conditions, enabling quick response actions. Local Display An LCD display is connected to the ESP8266 to provide local real-time readings of water quality parameters. This allows users to monitor data instantly without requiring access to cloud platforms. Overall Data Flow 1. Sensors measure water quality and send data to ESP8266. 2. ESP8266 processes the data and: • Displays it on the LCD. • Sends it to ThingSpeak via Wi-Fi. • Sends alerts via the GSM module when necessary.

Flowchart:

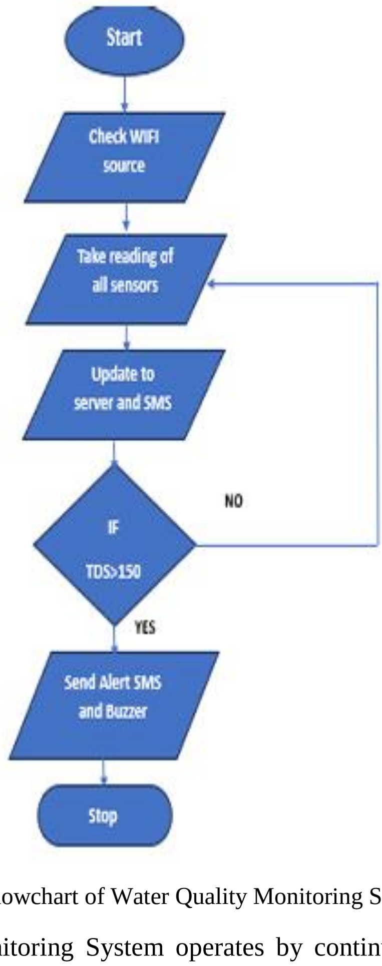

FIGURE 2. Flowchart of Water Quality Monitoring System.

Operation: The proposed Water Quality Monitoring System operates by continuously collecting real time data from multiple water quality sensors interfaced with the ESP8266 microcontroller. The system performs a series of tasks that ensure accurate monitoring, data transmission, and timely alerts to users. When powered on, the system initializes all hardware components including the ESP8266, pH sensor, temperature sensor, turbidity sensor, TDS sensor, LCD display, and GSM module. The Wi-Fi credentials are also configured to enable internet connectivity. The ESP8266 reads analog or digital signals from each sensor: • The pH sensor detects the hydrogen ion concentration to measure water acidity or alkalinity. • The TDS sensor calculates the total dissolved solids in the water. • The turbidity sensor evaluates the cloudiness or clarity of the water. • The temperature sensor monitors the thermal condition of the water. The collected sensor data is filtered and processed to ensure accuracy and reliability. The ESP8266 compares the real-time readings against predefined threshold values that indicate acceptable water quality. The processed data is displayed on the LCD screen, providing an on-site, real-time view of water quality parameters for local users or field technicians. The ESP8266 transmits the data wirelessly to the ThingSpeak cloud platform using its built-in Wi-Fi module. ThingSpeak stores and visualizes the data on dashboards, enabling remote monitoring through smartphones or computers. If any parameter crosses its safe threshold, the ESP8266 triggers the GSM module to send an SMS alert to predefined phone numbers. This ensures that the concerned personnel are immediately notified about potential water quality issues. The system runs in a loop, continuously monitoring, processing, and transmitting data at regular intervals. It is designed for energy-efficient operation, powered by a solar panel and battery setup, making it ideal for remote or unattended deployment.

Working Flow:

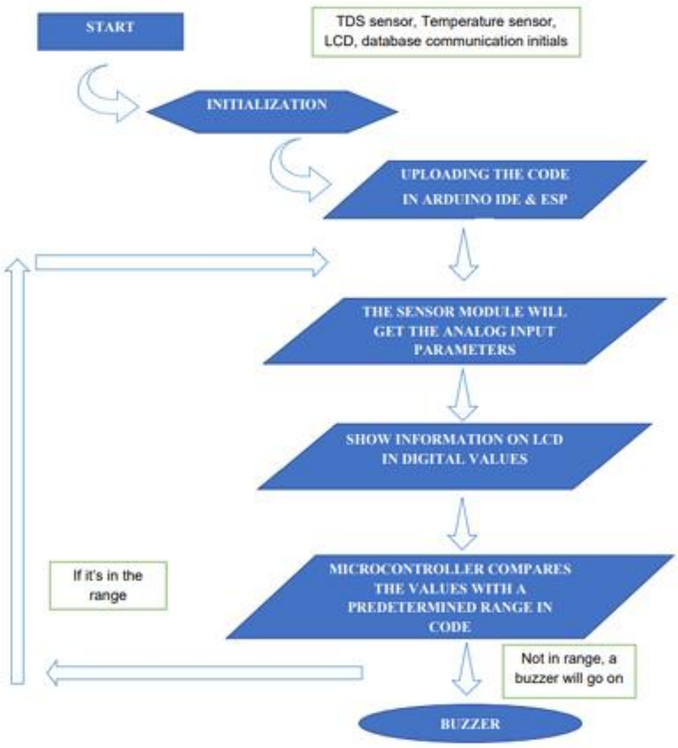

FIGURE 3. working flow of the device.

3. HARDWARE DESCRIPTION

ESP8266 Microcontroller: The ESP8266 is a low-cost, versatile Wi-Fi System-on-a-Chip (SoC) from Espressif Systems, often used for Internet of Things (IoT) applications, offering built-in TCP/IP networking and microcontroller capabilities.

FIGURE 4. ESP8266 Microcontroller

Technical Specifications: Processor: Tensilica L106 32-bit RISC processor , Wi-Fi Standard: IEEE 802.11 b/g/n, • Operating Voltage: 3.3V, Flash Memory: 512 KB or 1 MB (depending on the module) , SRAM: 64 KB, Clock Speed: 80 MHz, Operating Temperature: -40°C to +125°C, Programming Languages: AT commands, Arduino IDE, or Lua.

pH Sensor:

FIGURE 5. PH Sensor.

A pH sensor is an electronic device that gauges a liquid's acidity or alkalinity. The following are some essential pH sensor qualities and features: • Measuring principle: The concentration of hydrogen ions (H+) in a liquid is commonly measured by pH sensors using a glass electrode or a combination electrode. The voltage differential between the electrode and a reference electrode is measured to accomplish this. • Range: A liquid's pH can be measured with a pH sensor on a scale from 0 to 14. While values lower than 7 are considered acidic and higher than 7 are considered alkaline, a pH of 7 is considered neutral. • Calibration: pH sensors must be calibrated before being used. The pH of a known solution must be tested, and the sensor must be modified, in order to obtain an accurate value. • Temperature adjustment: pH sensors may have temperature adjustment to take into consideration temperature variations that may have an impact on pH readings. • Type of probe: There are various probe types that can be used with pH sensors, including immersion probes, in-line probes, and flow-through probes. Depending on the application and the liquid being tested, a certain type of probe will be utilised. • Maintenance: To get reliable readings, pH sensors need to be regularly maintained. This can entail routinely calibrating the sensor and frequently cleaning the probe and sensor cartridge. • Application areas: pH sensors are employed in a variety of applications, such as water treatment, the manufacture of food and beverages, medical equipment, and environmental monitoring. Output: Depending on the sensor type, pH sensors can produce analogue or digital output signals. A few examples of digital output signals are RS232, RS485, and USB. • Compatibility: Depending on the sensor type, pH sensors may be compatible with many controller types, including microcontrollers and PLCs. • Accuracy and precision: Depending on the sensor type and measurement range, pH sensors' accuracy and precision can change. Some sensors may have a +/- 0.1 pH unit accuracy, while others may have a +/- 0.01 pH unit accuracy. • Response time: Depending on the type of sensor and the measurement range, the pH sensor's response time can change. Some sensors might respond in just a few seconds, while others might take many minutes to respond.

Turbidity sensor:

FIGURE 6. Turbidity Sensor.

A turbidity sensor is an electronic tool that assesses the concentration of suspended particles, such as solids or bacteria, in a liquid. The following list of turbidity sensors' main attributes and traits: • Measuring principle: The number of suspended particles in a liquid is commonly measured using turbidity sensors using either light absorption or light scattering. • Range: Nephelometric turbidity sensors can measure a wide range of turbidity levels, from a few NTU to several thousand NTU. • Calibration: Turbidity sensors need to be calibrated before use. In order to get an accurate reading, the sensor must be adjusted after measuring the turbidity of a known solution0. • Sensitivity: Depending on the sensor type and the measuring range, turbidity sensors' sensitivity can change. Depending on the sensor, its sensitivity could range from 0.01 NTU to 1 NTU. • Application areas: Turbidity sensors are employed in a variety of applications, such as water and wastewater treatment, environmental monitoring, and the manufacture of food and beverages. • Probe type: Turbidity sensors may use immersion probes, in-line probes, or flowthrough probes, among other types of probes. Depending on the application and the liquid being tested, a certain type of probe will be utilised. • Maintenance: To obtain reliable readings, turbidity sensors need to be regularly maintained. This can entail routinely calibrating the sensor and frequently cleaning the probe and sensor cartridge. Output: Depending on the sensor type, turbidity sensors can provide analogue or digital readings. A few examples of digital output signals are RS232, RS485, and USB. • Compatibility: Depending on the sensor type, turbidity sensors may be compatible with various controller types, such as microcontrollers or PLCs. • Accuracy and precision: Depending on the sensor type and the measurement range, turbidity sensors' accuracy and precision can change. Some sensors may be accurate to within +/- 2%, while others may be accurate to within +/- 5%.

Temperature Sensor:

FIGURE 7. Temperature Sensor

Temperature sensor is a device, used to measure the temperature using an electrical signal. It requires a thermocouple or RTD (Resistance temperature Detector).It is the most common and most popular sensor. Temperature sensor, the change in the temperature correspond to change in its physical property like resistance or voltage. The measurement of the temperature sensor is about the coolness or hotness of an entity. The working of the sensor is the voltage that read across to the diode. If increment in voltage, then the temperature increases and there is a voltage decrement between the transistors terminals of emitter & base. That data saved by the sensor. If the difference in voltage is amplified, then analog signal is generated by the device, and it is directly proportional to the temperature.

Total Dissolved Solid:

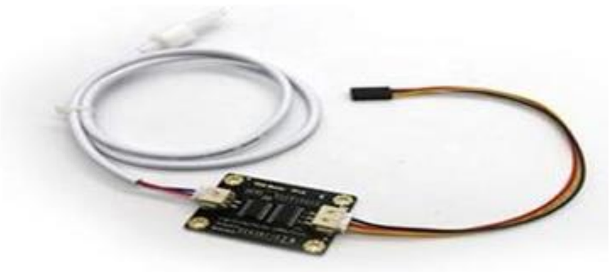

FIGURE 8. Total Dissolved Solid

The concentration of dissolved solids in a liquid is measured using an electrical device called a TDS (Total Dissolved Solids) sensor. The following are some of the main traits and qualities of TDS sensors: • Principle of measurement: To determine the number of dissolved particles in a liquid, TDS sensors commonly employ electrical conductivity. A modest electrical current is used to do this, and the conductivity that results is measured. • Range: Depending on the sensor, TDS sensors can measure concentrations at levels as low as a few parts per million (ppm) and as high as several thousand ppm. • Calibration: Calibration is usually necessary before using TDS sensors. In order for the sensor to deliver an accurate measurement, the conductivity of a known solution must be measured. • Temperature adjustment: To take into account temperature variations that may alter conductivity measurements, TDS sensors may have temperature adjustment. • Type of probe: There are various probe types that can be used with TDS sensors, including immersion probes, flow-through probes, and in-line probes. Depending on the application and the liquid being tested, a certain type of probe will be utilised. • Precision and accuracy: Depending on the sensor type and measurement range, TDS sensors' precision and accuracy can differ. Some sensors may be accurate to within +/- 2%, while others may be accurate to within +/- 5%. Application areas: TDS sensors are utilised in a variety of processes, such as industrial operations, food and beverage manufacturing, water treatment, aquaculture, hydroponics, and many other processes. • Maintenance: To provide reliable readings, TDS sensors need to be regularly maintained. This can entail routinely calibrating the sensor and frequently cleaning the probe and sensor cartridge. • Output: Depending on the type of sensor, TDS sensors can produce analogue or digital output signals. RS232, RS485, and USB are examples of digital output signals. •

Adaptability: Depending on the sensor type, TDS sensors may be adaptable to many controller types, including microcontrollers and PLCs.

GSM (Global System for Mobile Communication) module:

FIGURE 9. GSM Module

A GSM module works by connecting to the GSM network through a SIM card. The SIM card provides the module with a unique identification number, which is used to identify the device on the network. The GSM module then communicates with the network using a set of protocols, which allows it to send and receive data. The GSM network is a digital cellular network that uses a set of protocols to enable communication between devices. The network is divided into cells, which are each serviced by a base station. The base station communicates with the devices in its cell, and the cells are interconnected to form a network. The GSM module plays a crucial role in the communication between devices and the GSM network. It is responsible for establishing and maintaining the communication link between the device and the network. The module also handles the encryption and decryption of data, which ensures the security of the communication. There are different types of GSM modules, each with its own functionalities. Some modules are designed to handle voice communication, while others are designed for data communication. Some modules also have built-in GPS, which allows them to provide location information.

Liquid Crystal Display:

FIGURE 10. Liquid Crystal Display.

This LCD display module is a high-quality two line of 16 characters Display with on-board contrast control, backlight, and an I2C communication interface with an I2C interface. For Arduino beginners, a sophisticated LCD driver circuit connection is unnecessary. The true advantages of this I2C Serial LCD module are that it reduces circuit connections, saves some I/O pins on the Arduino board, and reduces firmware programming with the widely accessible Arduino library.

Software Description: The software aspect of the Water Quality Monitoring System is crucial to its functionality, enabling the microcontroller to gather sensor data, process it, and communicate with cloud platforms and mobile users. This software is developed using the Arduino IDE and is written in the C programming language, which provides an efficient and flexible environment for embedded programming on the ESP8266 microcontroller.

Programming:

FIGURE 11. Arduino IDE

Arduino IDE was selected as the development platform due to its simplicity, open source nature, and wide community support. • The code is written in C, using various external libraries for sensor integration, Wi Fi communication, and cloud data transmission. Libraries and Dependencies The following key libraries are utilized: • ESP8266WiFi.h – Enables Wi-Fi connectivity for the ESP8266. • ThingSpeak.h – Provides functions to send sensor data to the ThingSpeak cloud platform. • OneWire.h and DallasTemperature.h – For interfacing the DS18B20 temperature sensor. • Liquid Crystal.h – To operate the LCD screen. • Custom code and calibration logic for the pH, turbidity, and TDS sensors. • AT command support for communicating with the GSM module (e.g., SIM800L). Functionality Overview The software performs the following core functions: a) Sensor Data Acquisition • Analog and digital signals are read from the sensors connected to the ESP8266's GPIO pins. • Raw signals are converted into readable values using specific formulas and calibration values. b) Data Processing • The software validates and filters the data to reduce noise and ensure accuracy. • Each parameter (pH, TDS, turbidity, temperature) is compared with pre-set safe thresholds. c) Local Display • Sensor values are displayed on an LCD screen in real time. • The display refreshes periodically to show the most current readings. d) Wi-Fi Connection Setup • The ESP8266 connects to a configured Wi-Fi network on startup using credentials provided in the code. • Upon successful connection, the device is ready to transmit data to the cloud. e) ThingSpeak Cloud Integration • Real-time sensor data is uploaded to the ThingSpeak platform via HTTP. • Users can monitor values remotely through graphical dashboards and historical logs. f) SMS Alert System (GSM Module) • If any reading exceeds safe limits (e.g., pH < 6.5 or TDS > 500 ppm), the system triggers the GSM module. • Predefined messages are sent to registered mobile numbers using standard AT commands. 4.4 Security and Privacy • Data sent to ThingSpeak can be protected using private channel keys. • Access to sensitive data can be restricted to authorized users only.

4. RESULTS

The developed system was successfully implemented and tested under various water quality conditions. The main goal was to assess whether the system could accurately monitor water parameters (pH, TDS, turbidity, and temperature), transmit the data to the cloud using ESP8266, and send SMS alerts via the GSM module when water quality thresholds were violated.

5. ADVANTAGES, DISADVANTAGES AND APPLICATIONS

Advantages: Real-Time Monitoring: Provides continuous, real-time monitoring of water quality parameters, allowing immediate detection of contamination. Remote Data Access: Using IoT and cloud platforms like ThingSpeak, users can access data from anywhere via mobile or computer. Low Power Consumption: The system uses ESP8266 and a solar-powered battery setup, making it suitable for remote and off-grid locations. Automated Alerts: SMS alerts via the GSM module ensure users are notified instantly if water quality becomes unsafe. Cost-Effective: Affordable components make the system accessible for rural and small-scale applications. Scalability: Additional sensors or features (like GPS or filtration control) can be easily integrated in future upgrades.

Disadvantages: Sensor Calibration Needed: Sensors require periodic calibration to maintain accuracy, which may involve manual work. Network Dependency: Internet and GSM network availability is essential for data transfer and alerts; performance may drop in poor coverage areas. Environmental Interference: Sensor readings can be affected by temperature, fouling, or physical debris in the water. Limited Local Storage: The ESP8266 has limited onboard memory; without cloud connection, long-term data logging isn't possible. GSM Signal Fluctuation: In remote areas, the GSM module may experience delay or failure in sending alerts due to weak signal strength.

Applications: Drinking Water Monitoring: Ensures water supplied to homes and communities meets safety standards. Industrial Effluent Monitoring: Tracks waste discharge to prevent environmental pollution from industries. Smart Cities & Municipal Systems: Integrates into larger smart infrastructure for water management in urban areas. Environmental Research: Collects long-term data for ecological and pollution studies in rivers, lakes, and reservoirs.

6. CONCLUSION

In conclusion, the IoT-based water quality monitoring system presents a promising solution for addressing the limitations of traditional methods in monitoring and managing water quality. By leveraging the power of IoT technologies, the system enables real-time monitoring, data analytics, and decision support, contributing to efficient water resource management and safeguarding public health. So, the water quality testing is likely to be more economical, convenient and fast. The system has good flexibility. Only by replacing the corresponding sensors and changing the relevant software programs, this system can be used to monitor other water quality parameters. The operation is simple. This system could also be implemented in various industrial processes. The system can be modified according to the needs of the user and can be implemented along with lab view to monitor data on computers. While further research and development are required to refine the system and adapt it to specific contexts, the IoT-based water quality monitoring system represents a significant advancement in the field of water quality management. It offers a valuable tool for monitoring, analysing, and managing water quality in a more efficient, cost-effective, and data-driven manner.

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