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Smart Iot-Based Water Quality Monitoring System For Lake Management And Environmental Protection

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ABSTRACT

The conservation of water ecosystems and the availability of potable water sources depends on protecting the quality of aquatic resources such as ponds, rivers, and wells. As the traditional monitoring techniques comes with limitations, probability of inaccurate results, need heavy investment, we opted to this sophisticated tool to monitor. We are exposing the significant wireless-operated system when we are connected to the internet, and offline, it will store information in the smartphone by using the Arduino (ESP32) microcontroller. We are collecting the data using six sensors for important parameters: pH, TDS, turbidity, humidity, and temperature in Celsius and Fahrenheit by collecting the water samples across the pond. When the device is linked to a wireless network, the data will be kept in Think Speak servers for concurrent monitoring, and the gathered real-time information will be saved as text in the serial USB terminal of the mobile application. The proposed system was proven in testing the samples from lakes of Bengaluru Urban District, Karnataka: Seetharamapalya Lake, Nalluruhalli Lake and Hoodi Lake, and lakes of YSR Kadapa District, Andhra Pradesh, such as Chadipiralla Lake, Kamalapuram Lake and Devuni Kadapa Lake. Out of the tested, samples of Seetharampalya lake and Devuni Kadapa Lake are found not suitable for drinking due to high TDS. The proposed system is very accurate, as we are using sophisticated sensors that were tested before by real testing solutions to check accuracy, and they have proven correct. The proposed system is compact and easy to carry and can monitor remote areas compared with traditional methods to monitor water quality.

Keywords: *Water Quality Monitoring, IoT, microcontroller, PCB, Sensors, Real-time Data Logging, Wi-Fi Data Upload (ThingSpeak), Offline operation, Network Outage Recovery,*

INTRODUCTION

Water is crucial for life and environmental balance, but challenges like lack of water sources and contaminated water consumption cause diseases like cholera, diarrhea, and kidney diseases. By 2050, over 85% of freshwater will be needed for agriculture, making quality monitoring critical. This work proposes a low-cost water testing system for rural and urban areas, validating existing technical approaches for an affordable, effective monitoring solution. The twenty-first century has seen a remarkable surge in technological progress, but there has also been a concerning increase in pollution and global warming. The environmental challenges we face hurdles in this environment, such as the consequences of climate change, the pressure on restricted water supplies, and the expanding global population. [1]

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Importance of Water and Need for Monitoring:

Life and the natural world depend on water. Monitoring water sources regularly is essential to identify any contaminants that could compromise the water's purity. Maintaining the cleanliness of water is crucial for environmental balance, economic growth, and survival. Approximately two billion people consume contaminated water, and water scarcity is a global problem (WHO, 2021). This leads to diseases like cholera, typhoid, hepatitis A, diarrhea (which kills over 500,000 people a year), and renal issues (whose death rates are around the same as that of cancer, 2023). Many people use alternative, often untested water sources. Since agriculture will require more than 85% of freshwater by 2050, quality monitoring will be essential. Pollution was caused by past resource misuse and a lack of legal protections, but owing to EU regulations, areas like Timis County, Romania, are getting better [1].
This work validates technical approaches from earlier studies to create an affordable water monitoring solution by providing a simple, low-cost water testing instrument for isolated areas. Water is among the most essential natural resources made available to civilization. However, contamination and deteriorated water sources were accelerated by the rapid expansion of society and the broad human activities. The water quality described above must be monitored to identify any recurring variations in its parameters and guarantee its safety in real time [2]

Water Pollution Impact:

It is very important to ensure the effect that water pollution has on entire organisms. The world's population is growing at a rapid rate, making water management a crucial concern, particularly in the agricultural, industrial, and other sectors. Around the world, many people lack access to clean drinking water. Every month, a lot of the population is afflicted by different fatal diseases caused by polluted water. Research indicates that the only cause of nearly 5 million deaths each year is drinking tainted water. Giving kids access to drinking water can help prevent nearly 1.4 million child deaths, according to data from the World Health Organization[3] .According to PressReader, every day, over 14,000 people die from diseases caused by contaminated water, with nearly 580 of these deaths occurring in India [4] .

Role of Water Quality Monitoring:

The Central Pollution Control Board of India (CPCB) created a set of monitoring stations on different water resources entire the country, which monitor water quality on a yearly and monthly basis. This ensures that the water quality is maintained or restored to the desired level. Regular monitoring is needed to make an activity. Water quality monitoring aids in determining the type and extent of pollution control required, as well as the effectiveness of pollution control measures. Water quality monitoring systems must immediately detect any changes in water quality and communicate to officials so that appropriate action can be taken. The system was developed for continuous monitoring at the on-site and reports to officials on real-time water quality data. By computer/smartphone, officials can access the data. Our proposed system uses numerous sensors to monitor the parameters, measure the quality of water in real time for appropriate action, is cost-efficient and accurate, and requires minimal labor [2].

Water is the most critical component of the environment; the quality of groundwater and surface water has declined due to both human activity and natural. Natural factors that influence water quality include lithological, topographical, climatic, hydrological, and atmospheric factors [5,6]. Anthropogenic activities that hurt water quality include mining, livestock farming, waste production and disposal (industrial, municipal, and agricultural), and heavy metal pollution [7], increased sediment run-off or soil erosion caused by land-use change [6,8]. Nowadays, developing countries are also facing great challenges in improving water supply and sanitation and conserving water quality [9–11]. developed countries also faced issues such as nutrient enrichment and eutrophication of water resources for a long time, developed countries also struggled to improve and maintain their water growing populations required good water and better wastewater treatment systems [6,12].

Literature and Studies on Water Quality Monitoring:

Water is essential for life and human activity, but its quality is harmed by factors such as population growth, industrialization, and poor management. By 2030, the 2030 Agenda aims to reduce pollution and ensure access to clean water. Water quality monitoring is crucial for identifying pollutants and making informed decisions. Tamm, Nõges, and Jävet (1990–2002) showed the importance of monitoring dissolved organic carbon under changing climates. Traditional methods are costly and difficult, especially in remote areas with data gaps. Low-cost, in situ sensors and devices offer real-time, accessible alternatives, minimizing the need for lab analysis. The integration of IoT, cloud computing, and Big Data enables Smart Water Quality Monitoring Systems (SWQMS) to improve modeling and risk management. Studies emphasized the importance of modeling tools in protecting both the environment and human health [13,14] . Webb et al. (2011) and Hoolohan et al. (2020) discuss digital technology as an innovative and efficient solution to handle water issues. This review focuses on portable, low-cost in situ water quality monitoring technologies that can aid pond management and environmental protection [15,16].

Global Impact Statistics:

The environment is made up of five basic elements: soil, water, climate, natural flora, and landforms. Among these, water is the most essential ingredient for human survival. It is also critical for the survival of other living ecosystems [1]. Whether it is utilized for drinking, home use, food production, or recreation, safe and easily accessible water is essential for public health [17] Water pollution is a major global issue that requires continual examination and adaptation of water resource directorial principles at the international, national, and individual well levels. Water contamination has been identified as the biggest source of death and disease around the world. According to estimates, water contamination kills more than 14,000 people worldwide every day. In many underdeveloped countries, filthy or contaminated water is consumed without treatment. One factor contributing to this is public and administrative illiteracy, as well as a lack of a water quality monitoring system, both of which pose serious health dangers [18].

METHODOLOGY

Existing water quality monitoring system:

Existing pond-monitoring devices typically use a real-time clock (RTC) module, an OLED display, and an SD card interface to timestamp and store water quality data while offline, which is then uploaded to a cloud server such as Firebase once internet availability is restored. However, these systems have significant drawbacks, such as sophisticated hardware due to the addition of RTC and SD card modules, which raises the cost, size, and power consumption. Offline recovery is further limited because the SD card must be manually retrieved after disconnection, and there is no local display, prohibiting users from viewing data in the field without accessing the cloud or the SD card. OLED displays are prone to burn-in or image retention, which occurs when static images or text are displayed for extended periods of time, permanently damaging the screen and resulting in visible ghost images.

The present system is advanced than the existing, using a more compact method powered by an ESP32 and the comparison is shown in Table 1 represents the comparison between them. The 16×2 I²C LCD display consumes very less power than OLED displays. It consumes less electricity, especially when showing simple text. Instead of using an external real-time clock (RTC), this system uses time from mobile when connected by OTG, or if connected directly to power bank or mobile charger as power source then with Wi-Fi connection as connected to cloud based ThingSpeak's server-side RTC to offer exact timestamps. Sensor data is sent to USB serial and collected directly on a smartphone or laptop using a terminal program, eliminating the requirement for an SD card for offline storage. This design is streamlined and efficient, making it ideal for field applications.

Aspect	**Existing System**	**Proposed ESP32 System**
Timestamping	Requires an external RTC module	Uses ThingSpeak server-side RTC
Offline Data Storage	Requires SD-card module and manual retrieval	USB-serial logging directly to smartphone/laptop
Hardware Complexity	RTC + SD + microcontroller + LCD	Only ESP32 + LCD + sensors
Wi-Fi Recovery	Manual reconnection is needed after a Wi-Fi dropout	Automatic non-blocking Wi-Fi reconnection
Local Data Display	No local display; needs cloud access or SD-card readout	Real-time display on 16×2 I²C LCD
Portability	Bulky PCB with multiple modules	Compact 4×8-inch PCB, USB-powered
Power Consumption	Higher (due to RTC and SD modules)	Lower (no extra modules)
Cost	Higher cost due to additional components	Reduced cost (≈40% cheaper)
Data Continuity During Outages	Data buffering but no real-time view; SD-card retrieval needed	Local logging continues without interruption
Deployment Ease	Complex wiring, multiple modules to manage	Plug-and-play via USB, simple connections
Cloud Upload Flexibility	Often rigid, manual sync required after offline period	Seamless uploads automatically once Wi-Fi restores
Maintenance Overhead	High; SD-card swaps, RTC battery replacement	Very low; simple USB connection maintenance

Table 1: Comparison table for the existing and proposed systems

Proposed water quality monitoring system:

Figure 1 , Figure 2 , Figure 3 represents the proposed framework for water quality determination, photographic view of proposed water quality monitoring system, Circuit diagram design of the proposed system respectively.

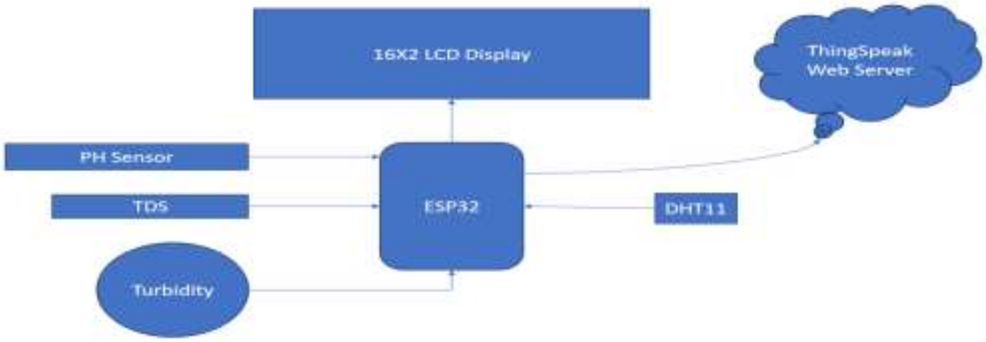

Figure 1: A proposed framework for determining the water

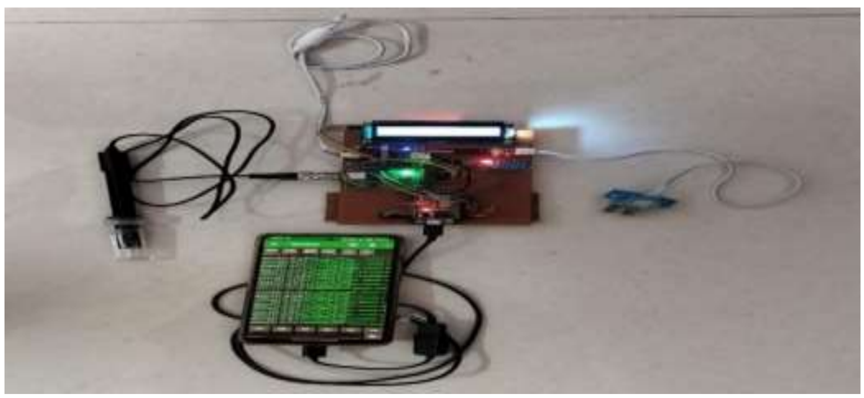

Figure 2: Proposed water quality monitoring system

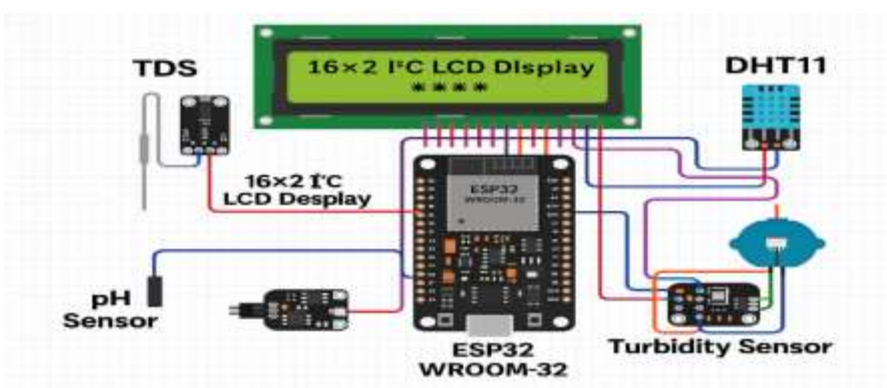

Figure 3: Circuit diagram design of the proposed system

For this experiment, we used three metrics to assess the quality of water. These features provide valuable insights into the overall health and condition of the water being analyzed. Each metric contributes to a better understanding of water quality by analyzing different characteristics.

A. PARAMETERS USED TO DETECT THE QUALITY OF WATER

1) pH :

The sensor will detect the amount of hydrogen ions present in water; the pH value is essential. The alkaline or acidic nature can be determined by measuring the pH values using the pH sensor. The pH value informs the hydrogen ion activity in a water solution. The pH value 7 indicates pure water; below and above 7 describe acidity and alkalinity, respectively. The pH indicated from 0 to 14. World Health Organization's guidelines define that pH between 6.5 and 8.5 is potable. The pH of pure water is neutral when the amounts of positive hydrogen ions (H^+) and negative hydroxide ions (OH^-) are equal. Acidic solutions have a pH of less than 7 and contain more hydrogen ions (H^+) than pure water. Basic (alkaline) solutions contain a larger amount of hydroxide ions than water, so the pH Value is generally greater than 7 (neutral).

2) TURBIDITY

Turbidity is a more accurate measurement type that determines the amount of invisible suspended particles in water. Because it shows that there are fewer suspended particles in the water, a lower turbidity level is a sign of cleaner water. Increased turbidity levels are linked to a higher risk of contracting watery illnesses like diarrhea and cholera. Turbidity is a straightforward and fundamental measure of water quality that has been used for decades to monitor drinking water, including filtered water. For aesthetic reasons, chemical and biological tests are not ideal, as almost all water systems, heavy amounts of suspended particles that might hinder.

3) TOTAL DISSOLVED SOLIDS (TDS)

Organic and inorganic substances, along with Salts, metals, Minerals, and anions, are among them. Units for TDS are ppm and mg/L. Because high TDS levels can indicate pollutants and have an impact on taste, odor, and suitability for drinking and industrial use, it is important to keep an eye on the water's TDS levels to check its quality. Unlike more traditional approaches to water quality monitoring, which depend on the manual collection of water samples, this system provides a way for assessing water quality that is both technologically sophisticated and completed instantly. The focus of the entire system architecture is the Internet of Things (IoT), a relatively recent concept in the software development industry. The hardware component consists of sensors for real-time measurements, an ESP32 for converting analog values to digital, an LCD for displaying sensor outputs, and Wi-Fi to establish communication between the software and hardware. The software component necessitates the development of an embedded C language program. This innovative technique provides a more successful strategy for addressing the problems related to water quality worldwide in the twenty-first century.

4) DHT11 Parameter

In the atmosphere DHT11 sensor can measure temperature and relative humidity at a time. The temperature between 0°C and 50°C (32°F to 122°F), and humidity from 20% to 80% can be measured by the DHT11 sensor. It transmits its data using a single wire and a simple digital signal. It is also factory calibrated, meaning it does not need to be calibrated again and is thus simple to interface. Understanding the weather and how it impacts various aspects, such as plant growth, human comfort, or the durability of materials, requires an understanding of temperature and humidity. While temperature indicates how hot or cold something is, humidity gauges the amount of moisture present in the atmosphere.

B. COMPONENTS/SENSORS UTILIZED

1) ESP32-WROOM-32

This microcontroller, the ESP32-WROOM-32, is powerful, inexpensive, and adaptable. Numerous wireless applications are perfect for it. It is appropriate for IoT and wireless projects due to its dual-core processor, built-in Wi-Fi, and Bluetooth. This has the capacity to work with lower power consumption that making the equipment run the equipment with even lower sources like mobile cells. The ESP32 has Ultra-low power 40 nm technology from TSMC because it is a standalone combination chip. In addition to having Bluetooth connectivity, it runs at 2.4 GHz. With careful craftsmanship, this chip is made to support a broad range of power profiles and application types, maximizing power performance along with RF performance, robustness, versatility, and dependability. This microcontroller is widely used in the market present day as it is an integrated solution for both Wi-Fi and Bluetooth integrations. the ESP32 requires fewer than ten external components. Figure 4 shows the picture of ESP 32 microcontroller.

Figure 4: ESP32 Microcontroller

2) 16×2 I²C LCD DISPLAY

LCD stands for liquid crystal display. In this work, we are using a 16x2 screen that can show up to 16 characters in two rows, for a total of 32 characters on the screen. The outcomes of alpha-numeric data are displayed using it. Additionally, symbols will be shown on the screen using it. Eight pins are located in each of its two rows, for a total of 16 pins. Data collecting, power supply, and control signals are all connected to these 16 pins. The contrast slider on the LCD screen allows you to adjust the contrast between the text and background. You can alter the voltage across the liquid crystals to regulate the content's readability. The 16×2

Figure 5 : 16×2 I²C LCD Display

LCD panels' small screen size and low resolution are drawbacks, and they might not be appropriate for showing intricate images or a lot of data. Figure 5 shows the concerned LCD display.

This 16×2 I²C LCD display is a cost-effective and simple alternative to OLED displays. It provides an inexpensive alternative for showing basic text, such as sensor readings, while avoiding the increased prices and power consumption associated with OLED displays. It is suited for situations where affordability and simplicity are important considerations. The 16×2 LCD display is a stable option for projects that do not require high resolution or color displays, unlike OLED displays that can experience burn-in and shorter lifespans. It also consumes little power.

3) PCB BOARD

Printed circuit boards (PCBs) are electronic structures that use copper conductors to electrically connect components. Additionally, PCBs give electronic components mechanical support so that a device can be enclosed. Figure 6 shows the PCB used in work.

Various kinds of PCBs are in use such as PCBs with one side, two sides, or several layers Flex PCBs, rigid-flex PCBs, and flexible printed circuit boards PCBs with metal cores are also known as insulated metal substrates (IMS). These include substrate-mimicking UHDI PCBs, HDI PCBs, and ceramic PCBs.

Figure 6: 4 ×8 PCB

4) pH SENSOR

The alkaline or acidic nature can be determined by measuring the pH values using the pH sensor. The number of hydrogen ions (H+) in water is measured by a pH sensor to determine how acidic or alkaline the water is. The pH of the water determines the voltage that this electrode generates. Throughout the completion of the electrical circuit, a reference electrode provides a constant reference voltage. pH sensors are widely used in many different industries, such as agricultural, food and beverage manufacturing, industrial, and water quality monitoring. There are several types of pH sensors, such as combination probes (glass electrode and reference electrode combined), spear tip sensors for solid-state penetration, and micro-pH sensors for tiny samples. Figure 7 shows picture of the pH sensor.

Figure 7: pH Sensor

5) DHT11 Sensor

In the atmosphere DHT11 sensor can measure temperature and relative humidity at a time. Since the sensor has an 8-bit microscope output and a negative temperature coefficient (NTC) for measuring temperature, the temperature and humidity readings sent to the microcontroller are serial data. The sensor reads the same temperature and humidity values. It is also factory calibrated, meaning it does not need to be calibrated again and is thus simple to interface. Figure 8 shows the picture of DHT11 sensors.

According to Zin Myint et al. (2017), the sensor accurately measures temperatures ranging from 0 to 50

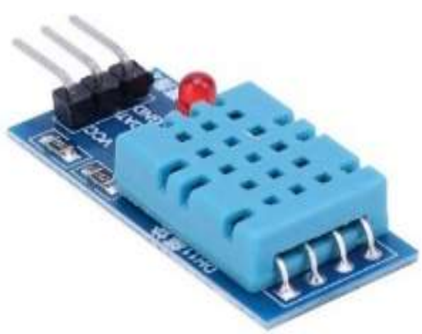

Figure 8: DHT11 (Temperature & Humidity Sensors)

degrees Celsius and humidity levels ranging from 20% to 90% [19]. In order to guarantee that the pH and turbidity sensors continue to operate correctly over time, the sensor is used to measure the temperature of the atmosphere. According to Cloete et al. (2014), temperature readings can also be used to determine the types of marine life that can survive in the ocean [20]

6) TURBIDITY SENSOR

By detecting a liquid's cloudiness or haziness, a turbidity sensor essentially counts the number of suspended particles in that liquid. A pH sensor, on the other hand, measures the level of acidity or alkalinity in a liquid. Both are crucial for water quality monitoring and remediation. Turbidity sensors use light scattering to quantify the quantity of suspended particles in a liquid. Figure 9 shows the picture of the turbidity sensor.
Measurements are made of the amount of light dispersed by water particles when a light beam is focused on

Figure 9: Turbidity Sensor

the water. The intensity of diffused light increases with turbidity. Nephelometric Turbidity Units (NTU) and Formazin Turbidity Units (FTU) are the two units used to measure turbidity. Wastewater treatment, industrial operations, and water quality sampling all make use of the turbidity sensor.

7) TDS SENSOR

A TDS (total dissolved solids) sensor measures the number of dissolved solids in water, which determines the quality of the water being measured. It measures the electrical conductivity of the solution because dissolved particles increase the electrical conductivity of water. Metals, minerals, salts, and other dissolved compounds may all be measured with TDS sensors.

Figure 10: TDS Sensor

The electrical conductivity of the water can be measured by this TDS sensor. Dissolved solids improve conductivity, which allows the sensor to measure the TDS level. In Aquaculture, hydroponics, and water treatment applications, TDS sensors are used to verify the safety and purity of water. Internationally, TDS levels are measured in parts per million (ppm) or milligrams per liter (mg). Figure 10 shows the picture of the TDS sensor.

8) WI-FI:

During startup, the proposed system attempts to establish a Wi-Fi connection within a 15-second interval. If the connection fails, it will attempt to rejoin in the background while not interfering with local data sampling and logging. This non-blocking method ensures that the system may continue to collect and store data even if the Wi-Fi connection is briefly broken.
For continuous data logging and communication, the system employs a two-phase Wi-Fi approach. The ESP32 attempts to establish a 15-second Wi-Fi connection once the system has powered on. Every five seconds, if it disconnects, it tries to reconnect without interfering with the gathering of sensor data or display updates. The system transmits data to ThingSpeak every 20 seconds after Wi-Fi is restored. It continues to log data via USB serial even in the absence of Wi-Fi to ensure that nothing is lost.

9) THING SPEAK

ThingSpeak is one of the IoT data collection applications that collects the data and displays it in a graphical representation, and stores it. Sensors such as voltage, moisture, pH, turbidity, GPS, humidity, temperature, and distance etc. The data collector takes data from edge node devices, such as the Node MCU/ESP8266, and can be adjusted for historical analysis via software. ThingSpeak is shown in Figure 11 . To begin, the user must provide their server login information. ThingSpeak activity comprises essentially a channel containing

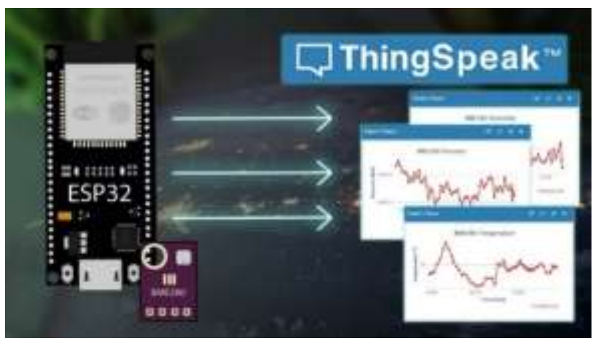

Figure 11: ThingSpeak

data and status fields. After constructing a ThingSpeak channel, data is updated, processed, and analyzed with MATLAB code. The data is then acted upon through tweets and alerts.

C. ALGORITHM OF WATER QUALITY MONITORING SYSTEM

The first stage in the system's functioning is to turn on and initialize all the associated sensors, including the DHT11 temperature and humidity sensors, the pH, TDS, and turbidity sensors. Following initialization, the turbidity, pH, and TDS values are displayed on the 16x2 LCD display. After determining whether it is powered by a mobile OTG connection, the system uploads sensor data (temperature, humidity, turbidity, pH, and TDS) to the Serial USB Terminal every three seconds. When the system is fueled by a wall charger or battery bank, it verifies the Wi-Fi connection. Every 20 seconds, the identical set of sensor information is sent to ThingSpeak if Wi-Fi is accessible. The system keeps tracking and displaying the data regardless of the mode, doing this again in a loop. Figure 12 shows the flowchart of the proposed water quality monitoring system.

The algorithm begins by switching up the device and initializing all sensors required for water quality monitoring. Based on the power supply and Wi-Fi availability, it selects the appropriate mode (Mobile OTG or Wi-Fi) and uploads sensor data either to a Serial Terminal or to ThingSpeak at defined intervals, while continuously displaying and updating the values.

Algorithm:

Step 1: Start the system.
Step 2: Initialize the following sensors:
pH Sensor, TDS Sensor, Turbidity Sensor
DHT11 (Temperature and Humidity Sensor)
Step 3: Display pH, TDS, and Turbidity values on the 16x2 LCD.
Step 4: Check the power source:
If powered via Mobile OTG, go to Step 5.
If powered via Power bank/Wall Charger, go to Step 6.
Step 5: Mobile OTG Mode:
Upload pH, TDS, Turbidity, Temperature, and Humidity values to the Serial USB Terminal Every 3 seconds
Step 6: Check Wi-Fi connection:
If Wi-Fi is ON, go to Step 7
If Wi-Fi is OFF, go to Step 8.
Step 7: Wi-Fi Mode:
Upload pH, TDS, Turbidity, Temperature, and Humidity values to ThingSpeak every 20 Seconds.
Step 8: Continue monitoring and displaying data.
Step 9: Repeat Steps 2–8 continuously in a loop.

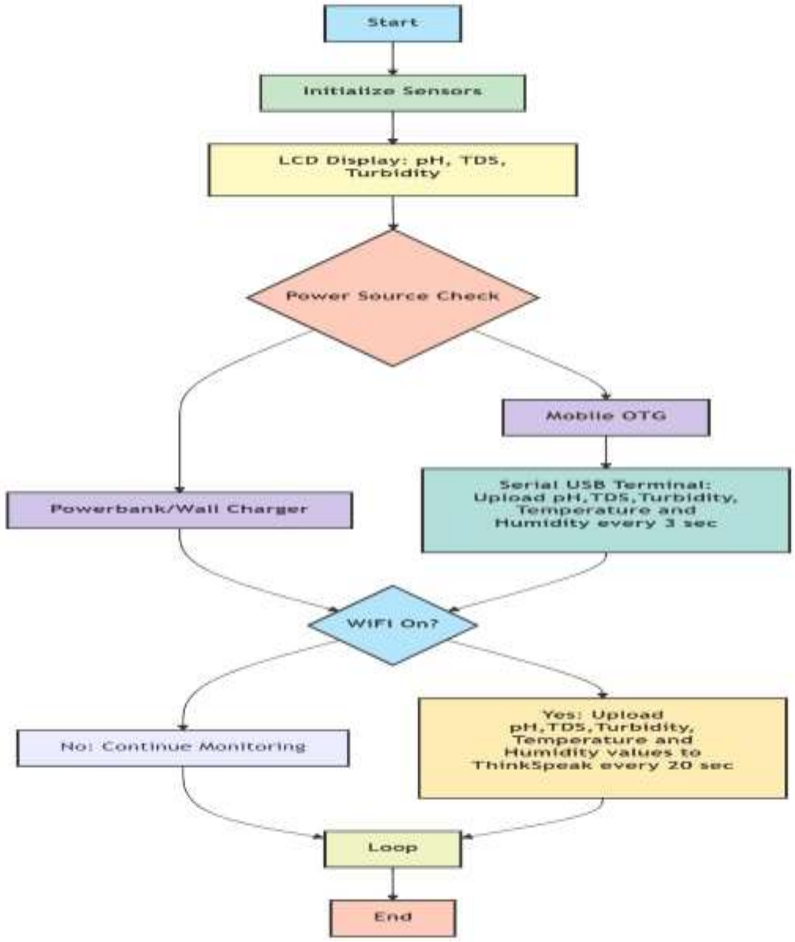

Figure 12:Flow chart of water quality monitoring

DEPLOYMENT

Six ponds in two Indian states—Andhra Pradesh and Karnataka—were tested with the water quality monitoring system.

Tested Lakes in YSR Kadapa District, Andhra Pradesh.

1. Chadipiralla Lake, (Rural)
2. Kamalapuram Lake (Rural)
3. Devuni Kadapa Lake (Rural)

Tested Lakes in Bengaluru Urban District, Karnataka.

4. Seetaramapalya Lake (Urban)
5. Nalluhalli Lake (Urban)
6. Hoodi Lake (Urban)

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As the system deployment figures demonstrate, this configuration makes it possible to compare the quality of water in various geographical locations and environmental conditions.

Figure 13 shows the tested lakes of YSR Kadapa District in state of Andhra Pradesh. These rural locations provide insight into water conditions in less industrialized and more agricultural regions. Monitoring in these areas helps evaluate how farming practices, groundwater usage, and natural factors influence water quality in village and countryside settings. Figure 14 Figure 15 Figure 16 shows the pH, TDS, Turbidity, Temperature and Humidity values for the tested lakes in the YSR Kadapa district of Andhra Pradesh, India.

Chadipiralla Lake (Lake 1) *Kamalapuram Lake (Lake 2)* *Devuni Kadapa Lake (Lake3)*

Figure 13: Tested Lakes in YSR Kadapa District, Andhra Pradesh, India.

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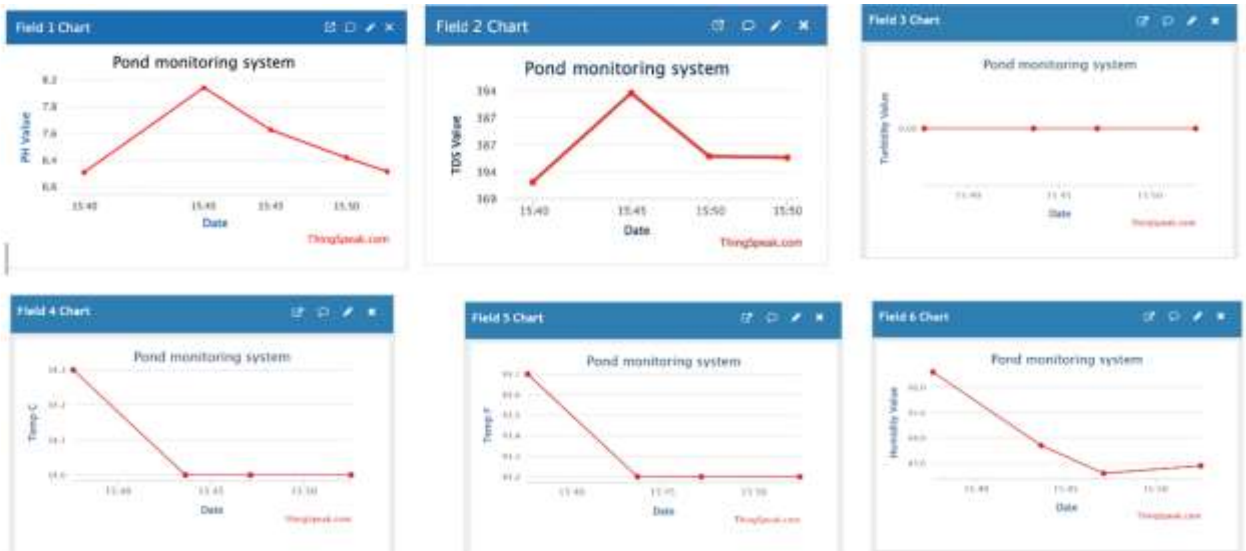

Figure 14: pH, TDS, Turbidity, Temperature and Humidity values at Chadipiralla Lake (Lake-1).

Figure 14 represents that the pond monitoring system shows the water quality is in a good and stable condition. The pH level averages around 7.45, which is right where it should be, indicating the water is chemically balanced. The TDS (Total Dissolved Solids) reading is 384 ppm, which falls within the safe range and suggests a moderate amount of minerals—nothing to worry about. The water is also very clear, with no visible particles, as the turbidity reading is a perfect 0 NTU. Environmental conditions are also normal, with a warm temperature of 34.15°C and humidity at 45%. Overall, the sensors confirm that the water is clean, safe, and the system is working smoothly.

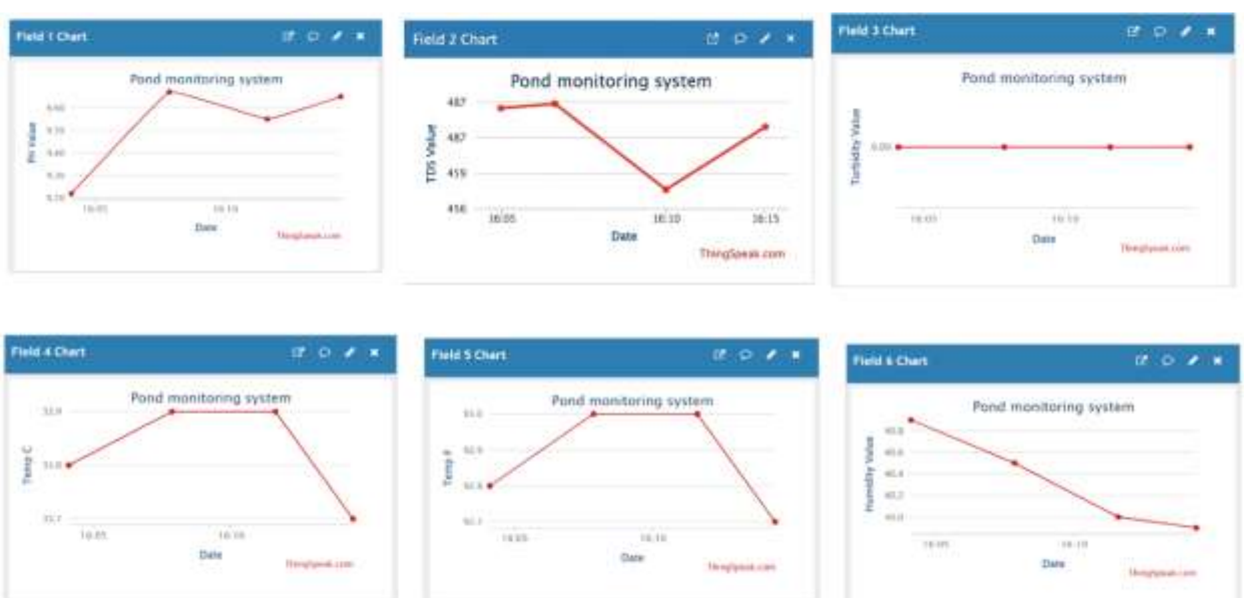

Figure 15: pH, TDS, Turbidity, Temperature and Humidity values at Kamalapuram Lake (Lake-2).

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From the Figure 15 , its clear that the pond monitoring system for the lake 2 showing that the water has a high pH level (avg. 9.4), which exceeds the WHO safe range (6.5–8.5) and makes it unsuitable for drinking. However, TDS levels (avg. 473 ppm) are within the acceptable limit (<500 ppm), and turbidity is excellent at 0.00 NTU, indicating clear water. The temperature (avg. 14°C) and humidity (avg. 40.4%) are stable, with no environmental concerns noted. Overall, while the water is clear and chemically balanced in terms of dissolved solids, the high alkalinity makes it unfit for consumption.

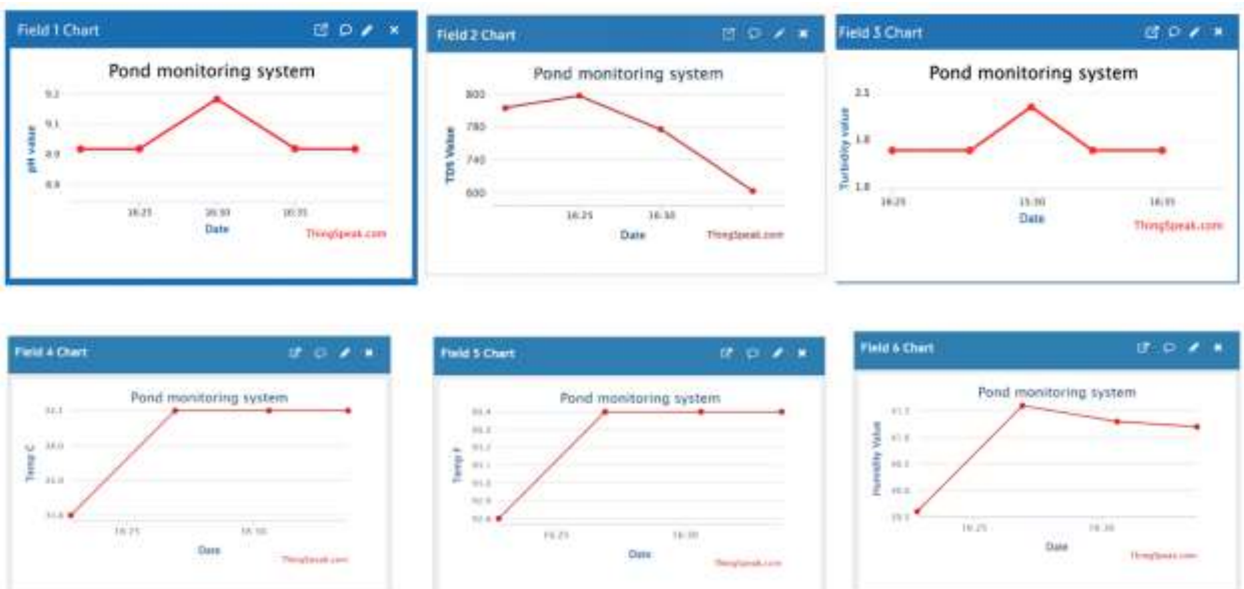

Figure 16: pH, TDS, Turbidity, Temperature and Humidity values at Devuni Kadapa Lake (Lake-3).

Figure 16 shows that for the lake 3, the water TDS is slightly higher than the WHO-recommended range for drinking water, at about 790 ppm, according to data from the pond monitoring system. The average TDS level is 720 ppm, which is significantly higher but still within the wider permitted range. At 1.75 NTU, the turbidity is moderate, which is not ideal but acceptable. The water's temperature of 34.2°C is warm, which may affect other aspects of its quality, and its humidity of about 40.5% is typical of the environment. Although the water may still be suitable for other non-potable uses, its increased pH and TDS make it generally unsafe to drink untreated.

Figure 17 shows the tested Lakes in the Urban Bengaluru Karnataka state, India. These rural These locations represent city-based environments where the water quality monitoring system was deployed. Urban ponds are typically subject to pollution from residential, industrial, and vehicular activities, making them important sites for assessing the impact of urbanization on water quality. Figure 18 Figure 19 Figure 20 shows the pH, TDS, Turbidity, Temperature and Humidity values for the tested lakes in the urban Bengaluru, Karnataka, India.

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Seertaramapalya Lake (Lake 4) *Nalluruhalli Lake (Lake 5)* *Hoodi Lake (Lake 6)*

Figure 17: Tested Lakes of the Urban Bengaluru in the state of Karnataka, India

Based on Figure 18, the lake-4's water shows a high pH of 9.5 and turbidity at 14.5 NTU, both of which fall outside the safe range recommended by the WHO for drinking water. While the TDS level of 665 ppm is within acceptable limits, the elevated pH and cloudiness suggest the water may contain impurities and would need treatment before it's safe to drink. The temperature is quite warm at 31.9°C, and the humidity is a comfortable 35%, indicating typical environmental conditions. Overall, while the surroundings are fine, the water quality isn't suitable for drinking without proper purification.

Based on the monitoring data for lake-5, Figure 19 shows that the water appears safe for drinking according to WHO standards. The pH level averages 7.65, comfortably within the safe range of 6.5–8.5. TDS levels are stable at 423 ppm, well below the recommended threshold, and turbidity is excellent at 0 NTU, indicating very clear water. Environmental readings show a warm average temperature of 29.45°C (85.6°F) and moderate humidity at 55.24%, both typical and generally comfortable. While the water quality looks good based on key indicators, ongoing monitoring is important to ensure long-term safety.

Based on the pond monitoring system data for lake-6, Figure 20 shows that the water quality appears mostly safe with a few areas to watch. The pH level averages 8.7, slightly above the ideal WHO range but still generally acceptable. TDS is measured at 400 ppm, comfortably within safe limits, and turbidity stands at 1.4 NTU—just above the ideal, suggesting the water is a little cloudy but not unsafe. The environmental readings show a cool temperature of 10.7°C and moderate humidity at 59.5%. Overall, the water is in fair condition, with no major concerns but some parameters worth continued monitoring.

Figure 18: pH, TDS, Turbidity, Temperature and Humidity values at Seetaramapalya Lake (Lake-4).

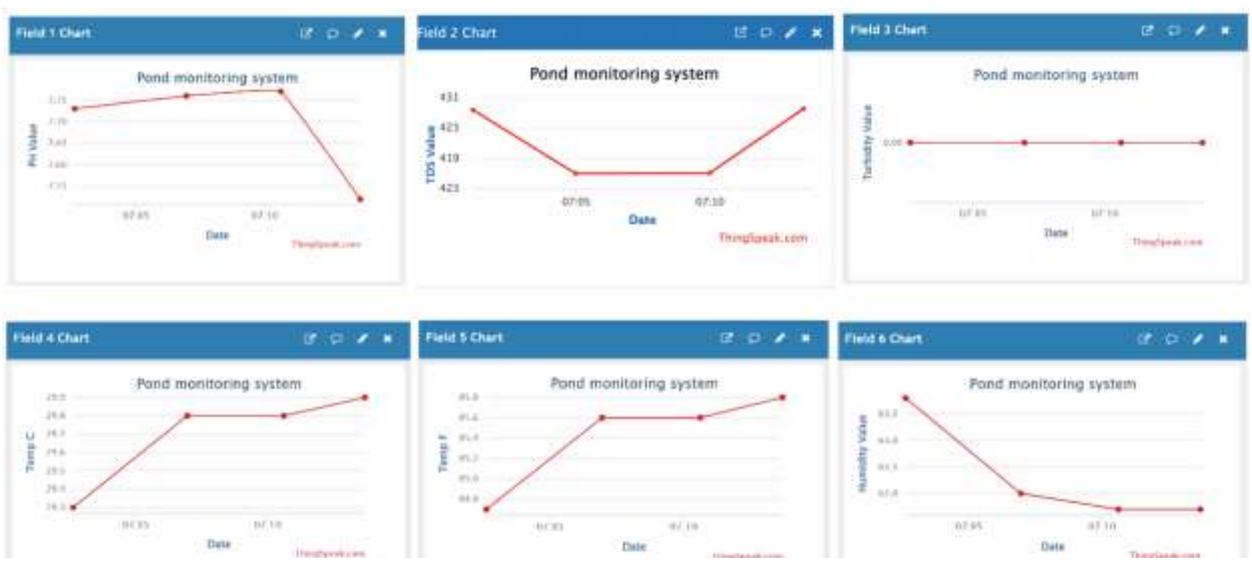

Figure 19: pH, TDS, Turbidity, Temperature and Humidity values at Nallur Halli Lake (Lake-5).

Figure 20: pH, TDS, Turbidity, Temperature and Humidity values at Hoodi Lake (Lake-6).

CONCLUSION

Traditional Pond monitoring setups have various drawbacks, which our ESP32-based IoT water quality monitoring solution addresses. By eliminating extraneous components such as an external RTC and SD card module, the design remains simple, low-cost, and easy to install while still delivering continuous data collection and accurate time-stamping via cloud services.
The system monitors pH, TDS, turbidity, temperature, and humidity in real time, and a sophisticated Wi-Fi reconnection approach ensures that data is logged even when the network fails. It supports both local data access via USB and cloud-based monitoring via ThingSpeak, making it suitable for a wide range of use cases. With its compact, USB-powered setup, it is ideal for remote fieldwork without the hassle of large batteries or SD card management. Field tests proved that the system provides accurate, high-quality water data even in tough environments. Overall, this study shows how IoT technology can deliver affordable, reliable, and portable water monitoring solutions that are perfect for pond management, aquaculture, environmental protection, and Smart farming.

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