

Smart Water Quality Monitoring System

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Abstract- Checking whether water is safe to drink normally means collecting a sample and sending it to a laboratory, and the answer can take hours or even days to come back. This paper describes a small Smart Water Quality Monitoring System that gives a quick first indication on the spot instead. An ESP32 microcontroller reads an analog Total Dissolved Solids (TDS) sensor and an analog turbidity sensor, converts their output voltages into ppm and NTU values, and places the sample in a Safe, Borderline or Unsafe band. The verdict is shown on a 16x2 LCD attached to the device and can also be sent to an online dashboard for later viewing. All parts are joined with jumper wires on a breadboard, so the prototype is easy to rebuild or change. The testing plan compares the device against a handheld reference meter using several kinds of water, and the paper explains how that comparison is carried out and reported. The system is meant as a screening aid and is not a replacement for certified laboratory analysis.

Keywords: smart water monitoring, ESP32, Total Dissolved Solids, turbidity, embedded hardware, IoT dashboard, water quality screening.

I. INTRODUCTION

Clean drinking water is something a household or a small institution cannot do without, yet the usual way of checking it still goes through a laboratory. A sample is collected, carried to a facility and analysed, and the result arrives later. That works for routine compliance checks, but it does not help someone who wants to know today whether the water in the overhead tank is fit to use. Two of the simplest indicators of water condition are how much material is dissolved in it and how cloudy it looks. TDS gives a rough idea of the salts and minerals present, while turbidity reflects suspended particles, silt or organic matter that scatter light. Neither reading tells the whole story alone, and a device that measures only one of them can miss a problem the other would have shown.

The system in this paper puts both sensors on one low-cost ESP32 board and adds something many similar student projects leave out, a display on the device itself. The person testing the water does not need to open an app or a web page. The Safe, Borderline or Unsafe result appears on a small LCD, and the same reading is also sent to an online dashboard for anyone who wants to look at the history. Because the build uses a breadboard and ordinary jumper wires, it can be copied and modified

without any custom circuit board. The aim of this work is not to replace a certified laboratory. It is to build an accessible, low-cost device that gives an immediate first reading using two well-understood sensing methods, and to describe how that reading can be checked against a reference meter.

II. LITERATURE REVIEW

Conventional water-quality assessment depends on collecting a sample and analysing it in a laboratory. Chia and Choong describe manual sampling and laboratory analysis as time-consuming and labour-intensive, and note that they do not give real-time data [1]. Sharma and colleagues add that the analysis of biological and chemical contaminants can need 24 to 48 hours, which leaves a window in which contaminated water may be used before the result is known [2]. IoT-based monitoring replaces much of this manual effort with sensors, a microcontroller and wireless communication. Jan, Min-Allah and Düstegör review IoT-based smart water-quality monitoring for domestic applications, covering recent techniques, trends and challenges [3]. Sharma and colleagues also trace how monitoring moved from early wireless sensor networks, which suffered from limited range, high power use and complex setup, to IoT systems

that allow remote monitoring through real-time connectivity [2]. On the hardware side, the ESP32 has become a favoured platform for new IoT systems because of its built-in Wi-Fi and Bluetooth and its low power use in sleep mode [2]. It is paired with TDS and turbidity sensors in several of the studies reviewed [1], [4], [5]. Jullio, Frianto and Lubis add a pH sensor and build a Thunkable interface for remote viewing [5], while Chia and Choong use the Blynk platform and add a temperature sensor [1].

Reported performance depends strongly on sensor quality and calibration. Chia and Choong report accuracies of 87.76% for TDS, 93.28% for pH and 95.35% for temperature [1]. Sharma and colleagues observed a gradual drift in low-cost TDS and turbidity readings during a 24-hour test and conclude that periodic recalibration is needed [2].

Taken together, the literature shows three things. Manual laboratory testing is slow for everyday checks. An ESP32 with TDS and turbidity sensors is a proven low-cost combination. Results are often viewed through a web page or an app, and their accuracy depends on calibration. These points motivate the on-device readout and the reference-meter comparison used in this work. The individual systems are compared more closely in the next section.

III. RELATED WORK

Quite a few recent projects have looked at ESP32-based water monitoring. A handful that are close to ours are summarised below.

Zafi, Saputra and Bianto built a TDS-only monitoring node for aquaculture ponds. The ESP32 reads the sensor, sorts the water into three status levels (safe, alert and poor) and sends the result to a web page [6]. It does its job well, but it has no turbidity sensing and no display at the pond, so the operator has to look at a screen somewhere else.

Arbiansyah, Bianto and Ardiansyah combined TDS and turbidity sensors on an ESP32 for residents of a housing complex who rely on river, lake and well water. The board processes the readings every three seconds and shows them on a website [4]. This is the closest match to our sensor pair, although the result is again only visible through a browser.

Nisa and Firmansyah paired a turbidity sensor with an ultrasonic water-level sensor on an ESP32 and sent the readings to the Blynk app. They tested four samples (mineral water, groundwater, tea and coffee) and found that the turbidity sensor could tell them apart [7]. At the more advanced end,

Sharma and colleagues describe a low-cost water quality monitor that adds on-device machine learning and cloud integration [2]. That is a useful direction, but it needs more hardware, more data and more effort to build than a simple threshold approach

Table 1: Comparison of the reviewed ESP32-based water monitoring designs with the proposed system.

Sr. No	System	Sensing	Output	Main limitation for our use
1	Pond TDS monitor [6]	TDS	Web page	No turbidity, no local display
2	Housing-complex monitor [4]	TDS + turbidity	Website	No on-device readout
3	Turbidity and water level [7]	Turbidity, level	Blynk app	No dissolved-solid data
4	On-device ML monitor [2]	Multi-parameter	Cloud and on-device ML	Higher cost and complexity
5	Proposed system	TDS + turbidity	LCD and IoT dashboard	Only two parameters

IV. RESEARCH GAP

Going through these papers, a few gaps stand out for a low-cost device that students can build. First, in most of the dual-sensor designs we reviewed, the reading goes to a web page or an app, so the person holding the sample gets no answer unless a phone or laptop is

nearby and connected. Second, designs that add more sensors, such as pH or temperature, tend to drop either the TDS and turbidity pairing or the local display. Third, the calibration steps are often described only briefly, which makes the reported numbers hard to reproduce. Finally, comparisons against a certified or calibrated reference meter across several different kinds of water are not always reported. This project tries to address these points in a modest way. It combines TDS and turbidity sensing with an immediate on-device readout, it describes the conversion and classification steps, and it sets out a protocol for comparing the readings with a reference meter across several types of water.

V. PROPOSED SYSTEM

1.Design Rationale

Two things drove the design. The parts had to be cheap and easy to find, and the finished device had to be useful without a phone or laptop. The ESP32 fits both. It has analog inputs for the two sensors, built-in Wi-Fi for the dashboard, and plenty of processing power for the simple conversion and threshold logic needed here. The TDS and turbidity modules are common analog boards that are inexpensive and well documented, which matters for a project that students should be able to repeat.

Figure 5.1 shows the overall arrangement. Water from the sample container reaches the TDS and turbidity sensors, and both send their analog output to the

ESP32, which is the only processing unit. The ESP32 shows the TDS value, the turbidity value and the Safe, Borderline or Unsafe status on the 16x2 LCD. A 5 V supply from a USB port or power bank runs the sensors and the board. The A0 labels in the figure mark the analog output pin of each module; on the ESP32 these lines land on GPIO34 and GPIO35, as Figure 5.3 shows in detail. Figure 5.1 concentrates on the on-device path, so the Wi-Fi link to the IoT dashboard is left out of it and is covered in Section 5.5.

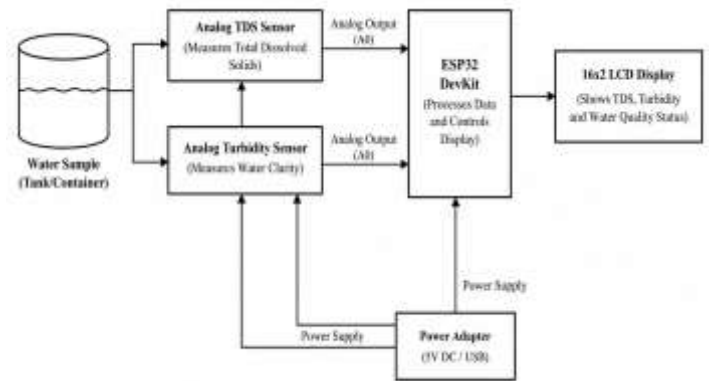


Fig. 5.1. System architecture of the Smart Water Quality Monitoring System.

1. Hardware Architecture

Table II lists the main components and what each one does. The wiring between them is described in Section 5.3.

Table II: Main components of the prototype and their roles.

Sr.No.	Component	Interface	Function in the system
1	ESP32 DevKit	Onboard ADC, Wi-Fi	Reads both sensor voltages, runs the conversion and classification, drives the LCD and sends readings to the dashboard.
2	Analog TDS sensor module	Analog input (GPIO34)	Gives a voltage that follows the electrical conductivity of the sample, from which the dissolved-solid level is calculated.
3	Analog turbidity sensor module	Analog input (GPIO35)	Infrared emitter and receiver pair whose output voltage falls as more suspended particles scatter the light.
4	16x2 I2C LCD (PCF8574 backpack)	I2C (GPIO21, GPIO22)	Shows the TDS value, turbidity value and the classification on the device.
5	Jumper wires and breadboard	Physical connections	Joins the modules without soldering so the build is easy to change.
6	IoT cloud dashboard	Wi-Fi	Keeps a time-stamped record of readings for remote viewing.

2. Circuit Connection And Sensor Placement

Both probes go directly into the water sample. The TDS electrodes and the turbidity sensor window

should be fully under water without touching the walls of the container. The wiring runs through a breadboard, with male-to-male jumper wires between the ESP32 and the power rails and male-to-female wires from the sensor headers to the breadboard. All

modules share a common ground with the ESP32. The LCD uses the I2C bus, so only two signal lines plus power are needed.

Figure 5.3 shows the connections. The TDS module, the turbidity module and the LCD take 5 V from the shared rail, which is fed by the USB power adapter that also supplies the ESP32 DevKit. The analog output of the TDS module goes to GPIO34, the analog output of the turbidity module goes to GPIO35, and the SDA and SCL lines of the LCD go to GPIO21 and GPIO22. Both analog inputs are ADC1 channels, which keep working while Wi-Fi is active. The turbidity module runs from 5 V and its output can rise above the 3.3 V limit of the ESP32 analog input, so that line needs a voltage divider before it reaches the pin. The divider is not drawn in Figure 5.3; it sits in the analog output line between the turbidity module and GPIO35.

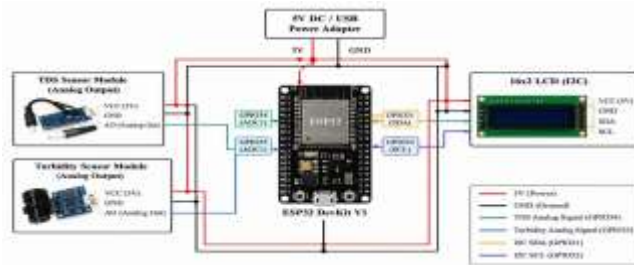


Fig. 5.3: Hardware connection diagram of the proposed system showing the jumper-wire connections between the power supply, the sensors, the LCD and the ESP32.

3. Signal Processing And Classification

Neither sensor gives a finished measurement. Each gives a voltage that has to be converted. For the TDS sensor, the analog reading is averaged over several samples to reduce electrical noise and then converted to ppm with the calibration curve supplied for the module. The readings are taken at room temperature and no temperature correction is applied, since the prototype has no temperature sensor. For the turbidity sensor, the voltage is converted to NTU with a two-point calibration line made beforehand from clear water and a known turbidity standard.

Once both values are available, the firmware compares them with the bands in Table III and decides whether

the sample is Safe, Borderline or Unsafe. These bands are the screening limits chosen for this prototype. They are informed by the WHO drinking-water guidelines [8], which treat high dissolved solids mainly as a taste and acceptability issue and ask for turbidity to be kept low, but the bands themselves are our own working choices for a low-cost sensor and not official pass or fail limits. The result and the two readings are shown on the LCD and sent to the dashboard every couple of seconds.

Table III: Screening bands used in the firmware, informed by WHO guidance.

Classification	TDS (ppm)	Turbidity (NTU)
Safe	up to 500	up to 5
Borderline	501 to 1000	5.1 to 10
Unsafe	above 1000	above 10

4. System Data Flow

The processing pipeline moves from sensor reading to averaging, then conversion to ppm and NTU, then classification, and finally the LCD update and cloud upload. Figure 5.5 shows these five stages in order. The pipeline is short on purpose. With only two input channels, a simple threshold check is enough, and a machine-learning model would add complexity without much benefit.

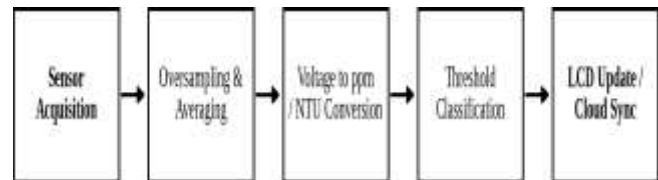


Fig. 5.5: Processing pipeline from sensor reading to the on-device and cloud output.

VII. METHODOLOGY

1 Sample Categories and Test Protocol

The testing protocol uses five categories of water that cover a realistic range of everyday quality: packaged mineral water, RO-purified water, municipal tap water, water stored in an overhead tank, and tap water deliberately adulterated with salt and a little soil. Ten readings are taken for each category, and each

reading is paired with a reading of the same sample from a calibrated handheld TDS and turbidity meter, which serves as the reference. Table IV gives the typical ranges expected for each category before testing.

Sample category	Trials	Typical TDS range (ppm)	Typical turbidity range (NTU)
Packaged mineral water	10	50 – 150	below 1
RO-purified water	10	20 – 80	below 1
Municipal tap water	10	150 – 400	1 – 5
Overhead-tank water	10	300 – 600	3 – 8
Adulterated water	10	above 1000	above 15

Table IV: Test categories and the ranges typically expected before testing.

2 Reducing Noise and Contact Errors

A few simple practices keep the readings consistent between trials. The probes are rinsed with distilled water and dried lightly between samples so that residue does not carry over. The turbidity sensor is best used away from strong ambient light, because

Sample category	Device TDS (ppm)	Ref. TDS (ppm)	TDS error (%)	Device turb. (NTU)	Ref. turb. (NTU)	Turb. error (%)	Class. match (of 10)
Packaged mineral water	104	98	6.1	0.9	0.8	12.5	10
RO-purified water	46	42	9.5	0.6	0.5	20.0	10
Municipal tap water	268	254	5.5	2.9	2.7	7.4	10
Overhead-tank water	452	428	5.6	5.6	5.2	7.7	9
Adulterated water	1185	1120	5.8	17.2	16.1	6.8	10
Overall	–	–	6.5	–	–	10.9	49 / 50

.Any disagreement in classification is most likely to appear for samples that sit close to a band boundary, such as a TDS value near 500 ppm, because a small

stray light reaching the optical window can shift the reading on clear samples. Averaging several analog readings per measurement reduces jitter from the ADC.

3 Evaluation Approach

For every trial, the device reading is compared with the reference meter reading for the same sample and the percentage error is calculated as the absolute difference divided by the reference value. The percentage errors reported in Table V are calculated from the ten-trial average of each category. The classification produced by the device is also compared with the classification that the reference readings would give under the same bands, and the number of matching trials is counted for each category.

VIII. RESULTS AND DISCUSSION

8.1 Sensor Accuracy

Table V records the outcome of the comparison for each sample category: the average of the ten device readings, the average of the ten reference readings, the resulting percentage error, and the number of trials in which the device classification matched the reference classification.

Table V: Device readings compared with the reference meter for each sample category

measurement error is enough to move the sample across the line. In this comparison the TDS error stays below about 10% in every category. The turbidity percentages look larger for the clean samples only

because the reference values are close to 1 NTU, where a very small absolute difference becomes a large percentage. Single-point infrared turbidity sensing is also known to respond to how evenly particles are spread through the sample, so the more uneven samples, such as the tank water and the adulterated sample, are the ones where larger turbidity error would be expected.

2 Response Time

Response time is measured by printing timestamps to the serial monitor. The first value is the time from sampling the sensors to the LCD update, and the second is the additional time taken to upload the reading to the dashboard, which depends on Wi-Fi strength. Table VI lists the averages over ten trials.

Table VI: Response time of the prototype.

Measurement	Trial 1 to 10 average (ms)	Notes
Sensor sampling to LCD update	1150	Includes averaging and conversion
Additional time for cloud upload	850	Varies with Wi-Fi signal strength
Total, sampling to dashboard	2000	Sum of the two stages above

3. Cost and Build

The prototype uses inexpensive, commonly available modules: an ESP32 board, two analog sensor modules, an I2C LCD, a breadboard and jumper wires. The total cost of the build was around INR 3,000. No soldering or custom circuit board is needed, which keeps the cost well below typical multiparameter water-quality instruments and makes the design easy to repeat.

IX. LIMITATIONS

The device has some limits that should be stated plainly. First, it measures only TDS and turbidity. It says nothing about pH, dissolved oxygen, heavy metals or bacteria, so a Safe reading is not the same as a certified potability result. Second, TDS readings depend on water temperature, and the prototype has no temperature sensor, so no correction is applied.

Third, both probes drift as electrodes and optical surfaces age or collect residue, so regular recalibration is needed. Fourth, the local classification works without a network, but the dashboard needs a stable Wi-Fi link. Finally, the two-point turbidity calibration is less accurate at the ends of the measuring range than a multi-point calibration would be.

1. Future Scope

There are several natural next steps. A temperature sensor would allow proper compensation of the TDS reading, and a pH sensor and possibly a dissolved-oxygen probe would make the device a more complete check. A small solar panel and battery would let the unit run unattended at a well, pond or storage tank. Alerts through a messaging app or phone notification when a reading enters the Unsafe band would make the dashboard more useful than a passive record. A multi-point calibration routine repeated at intervals would help keep the sensors accurate as they age. Several units could also be networked to monitor a housing complex, a campus supply line or a stretch of river.

X. CONCLUSION

This work set out to build a low-cost, self-contained device that gives an immediate reading of basic water quality. The prototype combines an ESP32, a TDS sensor, a turbidity sensor, a 16x2 LCD and an IoT dashboard, all connected with jumper wires on a breadboard. It classifies a sample as Safe, Borderline or Unsafe and shows the result on the device without needing a phone. The comparison with a reference meter across five kinds of water gives a measure of how far the readings can be trusted. The device is a quick screening tool and does not replace laboratory analysis, but it makes basic checking easy enough for more people to do.

1. Author Contribution

- Musab Shaikh: Software development, ESP32 programming, sensor data processing, LCD/Bluetooth programming and debugging.

- Anas Ansari: Wiring, component connections, hardware assembly, connection checking, troubleshooting and system testing.
- Kamish Khan: Hardware selection, system design, ESP32/expansion board, sensors, LCD and prototype development.

2. Funding

No external research funding is reported for this project.

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