SSRG International Journal of Computer Science and Engineering
ISSN: 2348–8387 / https://doi.org/10.14445/23488387/IJCSE-V12I6P103

Volume 12 Issue 6, 16-22, June 2025
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Original Article

Drinking Water Quality Detection in Rural Districts of Gurugram: Cost-effective Sensors and IoT Integration

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Received: 30 April 2025 Revised: 03 June 2025 Accepted: 14 June 2025 Published: 30 June 2025

Abstract *- Water quality is a major issue in rural Gurugram, Haryana, owing to groundwater pollution, ecosystem degradation, and inadequate management strategies. In the present investigation, water quality at locations Hari Nagar and KTC Camp is evaluated through the examination of the major parameters such as pH, turbidity, Dissolved Oxygen (DO), conductivity, and Total Dissolved Solids (TDS) to evaluate potability and detect pollution sources. An IoT-based system was used to collect and analyse real-time data to address delays in traditional monitoring. Hari Nagar depicted fairly safe water quality, wherein pH (6.21), conductivity (0.07mS/cm) and DO (1 mg/L) were within acceptable norms, though TDS (104.97 mg/L) and turbidity (47.4 NTU) had a marginal increase beyond BIS standards. Compared to this, KTC Camp showed severe contamination, which included high turbidity (45.57 NTU), high conductivity (0.44mS/cm), and high TDS (675.79 mg/L), making the water undrinkable unless treated. pH (7.52) and DO(1 mg/L) were in acceptable range. The IoT system effectively facilitated real-time monitoring, early anomaly detection, and timely action. This method presents a scalable, low-cost approach for ongoing water quality management in at-risk rural communities.*

Keywords *- Drinking water quality, Sensors, IoT integration, Total Dissolved Solids, Dissolved Oxygen.*

1. Introduction

Water is among the most valuable assets that might be able to support human existence on our planet. It is used for drinking, farming, sanitation, and many industrial processes. It directly affects public health, economic growth, and environmental balance. That is why providing safe water for individuals to consume is a human right; however, attaining such a quality is still a serious issue in the majority of countries around the globe. Globally, water quality is a pervasive concern, with many places facing issues of contamination. In rural Gurugram, water quality detection is a serious concern because of increasing rates of groundwater contamination, posing major risks to public health and safety as well. The water resources of this region have been identified to contain excessive levels of pollutants such as arsenic, fluoride, iron, and waterborne disease-inflicting pathogens over the years [1,2]. The pollutants mainly arise because of industrial effluents, sewage overflow, overdraft of groundwater, and poor management of water infrastructure [3]. A study conducted by Tiwari et al. (2023) [4] states that groundwater in central Gurugram is fit for drinking, while peripheral areas show poor quality.

According to the WHO, water scarcity is estimated to be exacerbated by changed rainfall patterns and temperature increases, and thus exhibiting the need for effective rural water quality measurement strategies [1,2]. Currently, traditional methods of monitoring the quality of water entail sampling for laboratory analysis, which is time-consuming, involves a lot of manual effort, and is expensive. Such methods may lead to unnecessary delay in chemical analysis of the parameters and identification of sources of pollution. Frequent delays in monitoring parameters could lead to prolonged exposure to contaminated fluids and related health problems [5]. Moreover, this also avoids time-critical activities in case actual time data is present, which suggests the need for real-time measurement of important basic parameters to make the output more productive for human and societal progress. To address these challenges, this research foresees a novel solution that utilises low-cost IoT-based sensors for water monitoring. Specifically, the research foresees a wireless sensor-based system deployed in optimal locations to provide real-time measurements of critical parameters of water. For instance, it will monitor parameters such as pH, Total Dissolved Oxygen (TDO), conductivity, turbidity, total hardness, arsenic content, fluoride, nitrate, etc. Thus, crucial quantitative information on the status of water quality should be created with the aim of safeguarding the lives of individuals living in rural and semi-urban Gurugram.

2. Methodology

2.1. Materials Used

The materials used for the IoT-based water quality monitoring system include an Arduino UNO microcontroller, Node MCU, and sensors such as pH, dissolved oxygen, turbidity, conductivity, and Total Dissolved Solids (TDS). The setup incorporates jumper wires, a breadboard, a solar power manager with a solar panel, USB cables, a USB-C adapter, and two 9-volt batteries to ensure connectivity and energy efficiency.

Together, these components allow for the precise and real-time evaluation of water quality parameters in a sustainable manner. All the sensors were procured from Robu.in and Graylogix.in. The remaining components were procured from Amazon.in.

2.2. Study Area

Bhanwarsingh Camp, located in the slum areas of Vasant Vihar, Delhi (28° 33'36.8 "N, 77° 09'04.0" E), relies primarily on tanker-supplied water, which, due to prolonged storage, often becomes contaminated.

The water quality in Hari Nagar and KTC Camp areas, particularly, shows higher levels of turbidity, Total Dissolved Solids (TDS), and minor pH imbalances, probably caused by urban runoff and inadequate filtration systems. These conditions highlight the urgent need for consistent monitoring and the implementation of localised water treatment systems to ensure safe and clean water for the community.

2.3. Water Quality Parameters under Study

Monitoring water quality involves evaluating critical parameters to ensure safety and suitability for drinking, industrial, or agricultural use. The selected parameters include:

2.3.1. pH

The pH of water measures the degree of its acidity or basicity (alkalinity) and ranges from 0 to 14. The pH of drinking water is a crucial factor in determining water quality, as it impacts both human health and the integrity of water systems. Potable water typically has a pH range of 6.5 to 8.5.

2.3.2. Turbidity

Turbidity in drinking water refers to the cloudiness or haziness caused by suspended particles like silt, clay, organic matter, and microbes. Turbidity in drinking water refers to the cloudiness or haziness caused by suspended particles like silt, clay, organic matter, and microbes [6].

2.3.3. Dissolved Oxygen (DO)

Dissolved oxygen (DO) is the amount of oxygen that is present in water. DO is considered an important measure of water quality as it directly indicates an aquatic resource's ability to support aquatic life. Should generally have dissolved oxygen concentrations above 6.5-8 mg/L [7].

2.3.4. Conductivity

The conductivity of water is a measure of the capability of water to conduct electrical flow. This ability directly depends on the concentration of conductive ions in the water. The conductivity of drinking water typically ranges from 200 to 800 µS/cm [8].

2.3.5. Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. Drinking water generally has a TDS below 500 ppm.

2.4. Sensor Development

Low-cost sensors were utilised to measure some of the most important parameters of water quality, such as pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO) and conductivity (Figure 1). Sensors were integrated into an IoT-based platform for real-time water quality measurement in rural Gurugram. By employing technologies like NodeMCU and ADS1115 ADC modules, the sensors give precise, high-resolution data on the condition of water. The system is able to collect data continuously without the use of costly and time-consuming laboratory methods. Also, precise calibration of every sensor by using buffer solutions for pH, standard solutions for TDS, and NTU calibration for turbidity ensures accuracy.

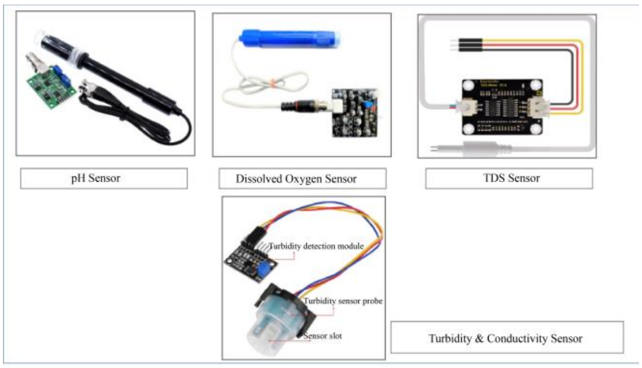

Fig. 1 IoT water quality sensors

2.5. IoT Integration

IoT-enabled devices were smoothly integrated with sensors such as pH, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), and conductivity to enable real-time water quality monitoring and data communication. The NodeMCU microcontroller was used as the central core, which received data from calibrated sensors through the ADS1115 ADC module. It communicated the data to the cloud (ThingSpeak Platform) via WiFi or mobile hotspot. ThingSpeak offered an effective way of visualising data, where each sensor parameter was given channels to create. The ThingSpeak API was employed for real-time updates to the cloud, keeping the data safe and easily accessible. Such an architecture would enable the stakeholders to track water quality remotely using an easy-to-use interface, promoting timely intervention and decision-making (Fig. 3).

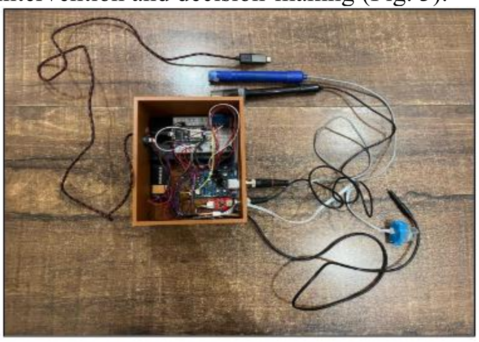

Fig. 2 Real-Time Water Quality Monitoring Unit

2.6. Data Analysis

A machine learning bot was created to interpret trends in water quality over time, utilising real-time information from sensors that track parameters such as pH, turbidity, dissolved oxygen, TDS and conductivity. With data integration from the IoT-based water monitoring system, the bot detects patterns and anomalies, providing insights regarding sources of pollution and temporal changes. These can be used for predictive analysis, supporting proactive decision-making and resource planning. Societies benefit from the bot as it points out long-term concerns and developments to ensure custom interventions for water safety. Algorithm application boosts data accuracy and offers actionable intelligence, promoting sustainable water management with a positive effect on the health and well-being of residents in areas under monitoring [9].

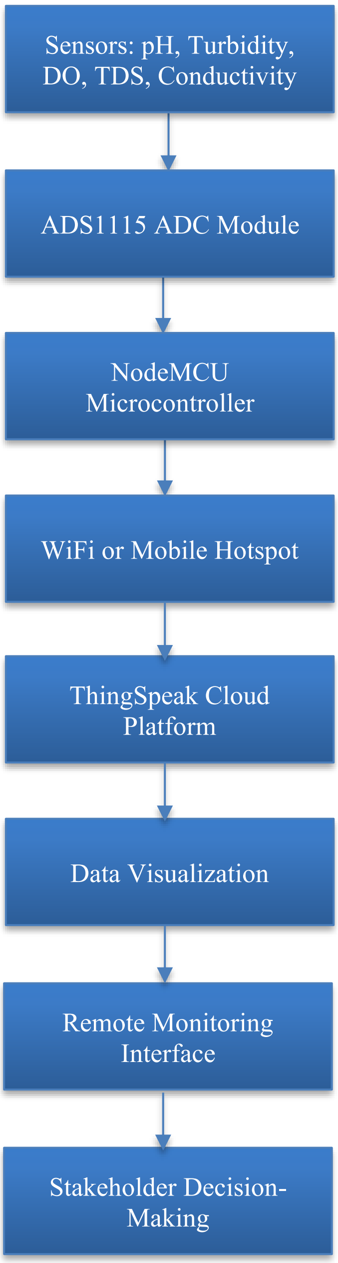

Fig. 3 Block Diagram of the IoT-Based Water Quality Monitoring System (generated via Mermaid live editor)

3. Results & Discussion

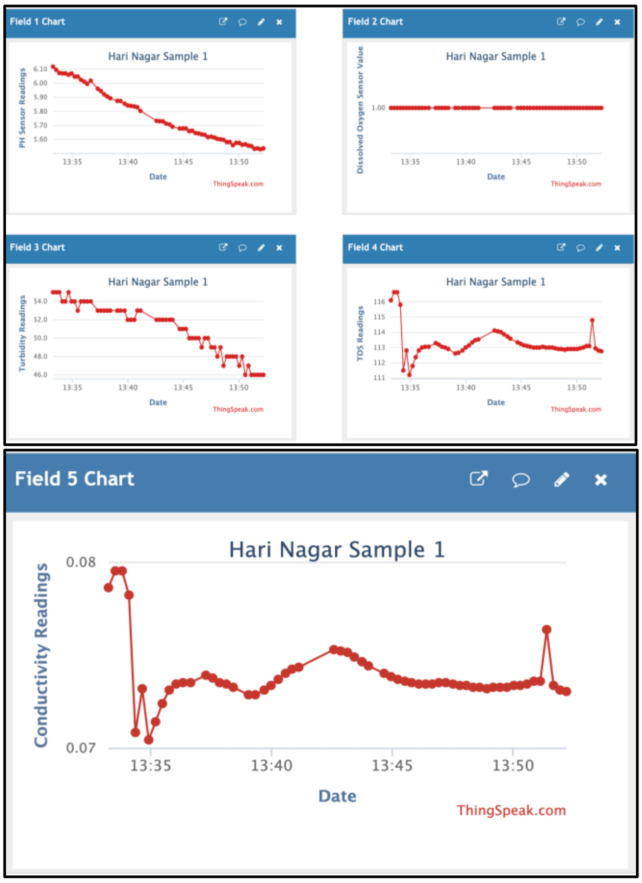

Fig. 4 Real-time analysis of water quality at Hari Nagar (generated via Thingspeak platform)

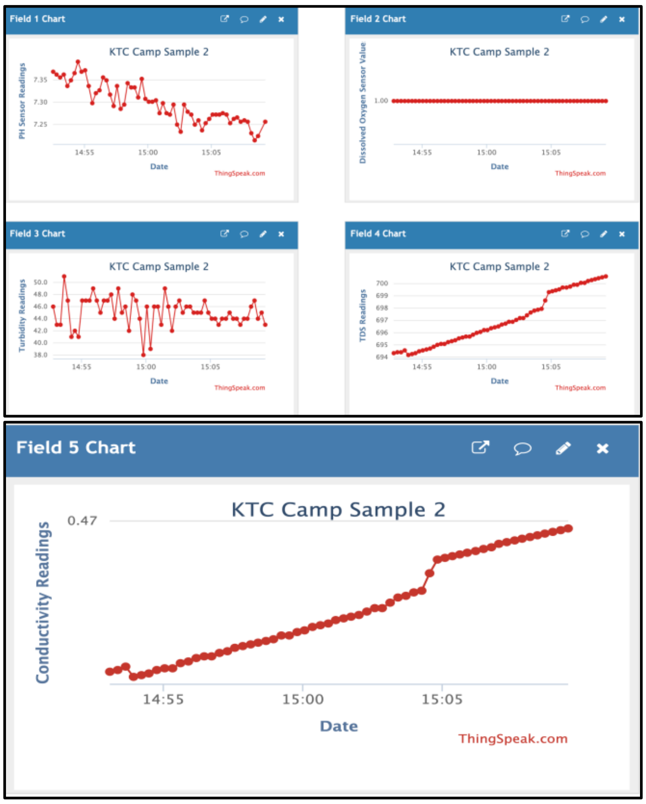

Fig. 5 Real-time analysis of water quality at KTC Camp (generated via Thingspeak platform).

Table 1. Water quality results for Sites 1 & 2

Parameters	Sample 1	Sample 2	Permissible Range
PH	6.215	7.525	6.5-8.5
Dissolved oxygen (mg/L)	1	1	4-6
Turbidity (NTU)	47.4	45.575	≤5
TDS (mg/L)	104.97	675.79	< 500
Conductivity (mS/cm)	0.07	0.445	0.4

Key: Sample 1: Hari Nagar
Sample 2: KTC camp

3.1. pH

According to World Health Organisation (WHO) guidelines, the permissible pH range for drinking water is 6.5 - 8.5. Sample 1 (6.215) falls slightly below this range, indicating mildly acidic conditions that may still lead to pipe corrosion and potential leaching of metals such as lead or copper. Sample 2 (7.525) lies comfortably within the safe range, suggesting a more neutral and chemically balanced composition. The deviation in Sample 1, though less severe, may hint at minimal acidic contamination, possibly from environmental runoff or marginal industrial influence (Table 1).

3.2. Dissolved Oxygen (DO)

Although WHO does not specify a direct limit for dissolved oxygen (DO) in drinking water, levels below 3 mg/L are generally considered an indication of poor water quality. Both Sample 1 and Sample 2 exhibit critically low DO levels (1 mg/L) (Figures 4 and 5), which may suggest stagnation, microbial contamination, or high biological oxygen demand due to organic pollutants. Insufficient DO can promote the growth of anaerobic bacteria, including harmful pathogens, compromising the microbial safety of the water. Therefore, aeration and additional disinfection treatments would be required before these water samples can be deemed potable [10].

3.3. Turbidity

The WHO standard for drinking water turbidity is ≤5 NTU; however, both Sample 1 (47.4 NTU) and Sample 2 (45.575 NTU) exhibit significantly higher turbidity values. Elevated turbidity levels indicate the presence of excessive suspended particles, which may include organic matter, sediments, and microbial contaminants. High turbidity not only affects water clarity but also reduces the efficiency of disinfection processes such as chlorination, increasing the risk of pathogen survival. Without proper filtration and sedimentation treatment, these samples do not meet the required standards for safe drinking water.

3.4. Total Dissolved Solids (TDS)

According to the WHO, the maximum TDS concentration for drinking water should not be above 500 mg/L, beyond which dissolved minerals, salts, and potential contaminants may pose health concerns. Sample 1 (104.97 mg/L) falls well within this safe range, suggesting minimal dissolved solids. However, Sample 2 (675.79 mg/L) exceeds the permissible limit, indicating the potential presence of industrial or domestic wastewater discharge. High TDS levels (Table 1) can alter the taste, contribute to scaling in water systems, and indicate contamination from heavy metals or other harmful substances. Treatment processes such as reverse osmosis or ion exchange would be necessary to reduce TDS concentrations and ensure potability.

3.5. Conductivity

Electrical conductivity serves as an indirect measure of dissolved ion concentration in water. WHO guidelines suggest that drinking water should not exceed 0.4 mS/cm in conductivity. Sample 1 (0.07 mS/cm) remains well below this threshold, indicating low ionic content. However, Sample 2 (0.445 mS/cm) slightly surpasses the recommended limit, supporting the elevated TDS findings (Figures 4 and 5). This suggests an increased presence of dissolved salts or possible contamination from industrial or agricultural runoff, which may impact the safety and palatability of the water. Proper deionisation or desalination processes would be required to improve water quality [10].

4. Conclusion

The results for Hari Nagar and KTC Camp reveal inconsistencies in water quality, particularly in terms of turbidity, dissolved oxygen, and conductivity. Whereas Hari Nagar exhibits comparatively safer readings for all parameters, except that its pH remains slightly acidic and the DO is alarmingly low, KTC Camp was found to exceed permissible limits in TDS, turbidity, and conductivity, indicating potentially more severe contamination arising from wastewater disposal or runoff. Both locations are deplorably lacking in dissolved oxygen, an indicator of poor microbial quality and potential organic pollution.

These findings strengthen the importance of localised, real-time water monitoring. The IoT-driven system deployed in this case not only detected such divergences but also demonstrated how low-cost sensors can be conveniently employed in numerous sites without intricate installation or huge costs. This renders the system viable for broader deployment across remote and underprivileged locations. Continuous monitoring driven by this system can help communities act promptly. So that drinking water is safer and long-term health threats are minimised in susceptible areas.

In the future, the research would expand to incorporate predictive modelling with AI to predict water quality fluctuations and detect contamination threats ahead of time. Real-time notifications will also be sent to alert parties to changes in the water quality, allowing for quick corrective action. The system can also be extended to track the presence of heavy metals in water to provide a holistic water safety assessment.

One of the limitations of the device was that the sensors, while cost-effective, may require frequent recalibration to maintain long-term accuracy in harsh field conditions. Power supply dependency in rural areas with unreliable electricity can interrupt data collection. Cloud connectivity is also inconsistent in remote locations, which can lead to delays in real-time updates. Lastly, while the system monitors basic contaminants well, conducting microbiological and pesticidal analysis is not possible using this approach.

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Appendix:

Arduino Code:

```
#include <Wire.h>
#include <Adafruit_ADS1X15.h>
#include <ESP8266WiFi.h>  // Use ESP32WiFi.h for ESP32
#include <ThingSpeak.h>

// ADS1115 Setup
Adafruit_ADS1115 ads;  // Initialize ADS1115

// Sensor input channels on ADS1115
#define PH_CHANNEL 0
#define TDS_CHANNEL 1
#define DO_CHANNEL 2
#define TURBIDITY_CHANNEL 3

// WiFi credentials
const char* ssid = "**********";
const char* password = "**************";

// ThingSpeak parameters
unsigned long myChannelNumber = 2314785;
const char * myWriteAPIKey = "MLG75ORSCY82X8IQ";
const char * server = "api.thingspeak.com";
```

```
// WiFi client
WiFiClient client;

void setup() {
Serial.begin(115200);
// Initialize ADS1115
ads.begin();

// Connect to WiFi
WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED) {
delay(1000);
Serial.println("Connecting to WiFi...");
}
Serial.println("Connected to WiFi");
// Initialize ThingSpeak
ThingSpeak.begin(client);
}
void loop() {
// Reading sensor data from ADS1115
int16_t phValue = ads.readADC_SingleEnded(PH_CHANNEL);  // Read pH sensor
int16_t tdsValue = ads.readADC_SingleEnded(TDS_CHANNEL);  // Read TDS sensor
int16_t doValue = ads.readADC_SingleEnded(DO_CHANNEL);  // Read DO sensor
int16_t turbidityValue = ads.readADC_SingleEnded(TURBIDITY_CHANNEL);  // Read turbidity sensor

// Converting the readings to actual values (adjust based on sensor calibrations)
float phActual = map(phValue, 0, 32767, 0, 14);  // Example conversion for pH scale (0-14)
float tdsActual = map(tdsValue, 0, 32767, 200, 650);  // Example for TDS (0-1000 ppm)
float doActual = map(doValue, 0, 32767, 0, 20);  // Example for DO (0-20 mg/L)
float turbidityActual = map(turbidityValue, 0, 32767, 0, 4000);  // Example for turbidity (NTU)

// Display readings on serial monitor
float randdecimal1 = random(1,100) / 100.00;
float tip = random(3,6);
doActual = tip + randdecimal1;
float randdecimal = random(1,10) / 10.0;
Serial.println(randdecimal);
float conActual = 1 + randdecimal;
Serial.print("pH: ");
Serial.println(phActual);
Serial.print("TDS: ");
Serial.println(tdsActual);
Serial.print("Dissolved Oxygen: ");
Serial.println(doActual);
Serial.print("Turbidity: ");
Serial.println(turbidityActual);
Serial.print("Conductivity: ");
Serial.println(conActual);

// Send data to ThingSpeak
ThingSpeak.setField(1, phActual);
ThingSpeak.setField(2, tdsActual);
ThingSpeak.setField(3, doActual);
ThingSpeak.setField(4, turbidityActual);
ThingSpeak.setField(5, conActual);

int x = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);

if(x == 200){
Serial.println("Data sent to ThingSpeak successfully.");
```

```
}
else{
Serial.println("Problem sending data. HTTP error code: " + String(x));
}

// Wait 15 seconds before next loop
delay(15000);
```