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# Design and Development of an Embedded System for Monitoring Water Quality

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**Abstract** **Original Research Article**

Water is one of the most pivotal fundamental resources for the existence of life, and remains vulnerable to contamination, posing a significant threat to global health. Approximately 3.5 million lives die annually due to polluted water. In this work, precise and reliable measurement techniques uses for leveraging the Internet of Things (IoT) to monitor water quality research endeavors to construct an intelligent embedded system dedicated to real-time water quality assessment. A wide range of sensors, including temperature, turbidity, pH, and total dissolved solids (TDS), are smoothly integrated into the system. These sensors operate harmoniously and capture critical data from various water sources. The obtained sensor data were stored meticulously in a robust database to facilitate subsequent analysis. The rigorous calibration processes validated the accuracy and reliability of these sensors across diverse water samples. Users gain convenient access to water quality metrics through an intuitive interface that is accessible through personal computers (PC) and mobile devices. The transformative power of IoT emerges as sustainability efforts and water management practices evolve. By harnessing IoT's capabilities, we propel water quality assessment to new heights, safeguarding lives and fostering a healthier and more resilient planet.
**Keywords**: Turbidity sensor, pH sensor, TDS sensor, Temperature sensor and water Monitoring.



## INTRODUCTION

In the relentless pursuit of human progress, one of the major and most prevalent problems is the preservation of the planet's most vital resource, water, which is imperiled by pollution and contamination. The insidious effects of water pollution not only compromise ecosystems but also threaten human health globally. To confront this environmental crisis, monitoring and safeguarding water quality is imperative (Kartik Maheshwari, 2021). However, rapid industrialization, agricultural runoff, improper waste disposal, and urbanization have brought havoc to waterways, rendering them repositories of toxins and pollutants (Jha *et al.,* 2020).

From heavy metals to chemical residues, the pollutants infiltrate aquatic habitats, disrupt biodiversity, and pose grave risks to human health through contaminated drinking water sources (Earnest *et al.,* 2021). The ramifications of water pollution are profound and far-reaching. Communities face heightened risks of waterborne diseases, compromised agricultural yields, and ecological degradation ( Sharma *et al.,* 2022).

Approximately 2.2 million people die from diarrhea every year, and most of them are young children in developing nations, according to data. People drink dirty or contaminated water with little to no pre-treatment in many developing countries because of low literacy levels and a lack of systems for monitoring water quality (Adeleke *et al.,* 2023). Moreover, marginalized populations bear the brunt of this environmental injustice, amplifying existing disparities in access to clean water and sanitation facilities.

Monitoring water quality is of significant importance and is increasingly recognized as a global issue concerning the availability and condition of water resources for various uses. Gathering dependable data on water quality stands out as a crucial element in safeguarding and formulating effective management strategies for our rivers and lakes (Fijani *et al.,* 2019).

Analyzing environmental data can also aid in comprehending the nature and extent of water quality issues, assisting policymakers in establishing feasible goals for enhancing water quality.

In the past, the assessment of water quality relied on manual methods involving the collection of water samples, which were then sent to laboratories for analysis. This approach is time-consuming, expensive, and requires significant human resources (Pasika and Gandla, 2020). In addition, conventional methods are prone to errors and inaccuracy and lack real-time data. The requirements of sample collection, transportation, preparation, and analysis consume quite a long time and resources in handling and obtaining reliable information for timely decision-making of possible courses of action.

Real-time monitoring and analysis of the physicochemical parameters of water could serve as a cornerstone in mitigating water pollution. With up-to-date and real-time information, remediation and prevention methods can be implemented to tackle the menace of water resource contamination and pollution.

The IoT-based system for continuous river water quality monitoring employs wireless technologies while focusing on low power consumption and cost-effectiveness of the system. The most important water quality metrics evaluated are pH, turbidity, temperature, and oxidation-reduction potential (ORP). However, the total dissolved solids were not incorporated into the device and were measured with fewer samples of minimal accuracy (Chowdury *et al.,* 2019).

(Wong Jun Hong *et al.,* 2019) have presented an Arduino-based solution that includes numerous sensors for monitoring water quality. The system performed well, but several inaccuracies, and it required human intervention. Despite these limitations, it serves as a strong basis for future advances in water quality monitoring technologies.

(Yue R., and Ying T., 2011) have developed a novel water quality monitoring system driven by solar energy and using a wireless sensor network (WSN). This low-cost and accurate solution uses Arduino to collect data from sensors measuring pH, turbidity, and oxygen density, which is then sent to a base station over the WSN. However, the method is inaccurate and omits crucial factors like TDS and temperature, which are required for comprehensive measurement of water quality.

This study highlights the critical importance of real-time monitoring and the application of IoT and embedded systems in the modern world. It focuses on the design and development of an advanced embedded system for measuring parameters related to water quality, such as pH, turbidity, TDS (Total Dissolved Solids), and temperature. Each parameter was measured using highly precise sensors, and the hardware and software were seamlessly integrated through a meticulously developed program. After calibration, the data collected from these sensors is processed by an Arduino microcontroller connected to an Ethernet shield. The processed data were then uploaded to a mobile device and webpage, allowing real-time monitoring through a global dashboard.

## METHODOLOGY

### Hardware implementation

The hardware implementation is designed with a processing unit and other blocks, as shown in Figure 1. The block diagram is divided into three sections: input, processing unit, and output, explaining the theory underlying real-time water quality monitoring. The input contains the sensing unit of the system with turbidity sensor B094W8YNFV, TDS sensor B08WC7MCZD, pH sensor 4502C, and temperature DS18B20. The microcontroller ATmega328p was interfaced with the sensing unit using proper protocols, and the sensed data was processed. The system collects water data from various sensors and water quality values in real time, transmitting them to the cloud via a MySQL database. The communication model (mobile phone, PC) transfers data from the microcontroller to a remote system, and an LCD (liquid crystal display) 20x4 is also used to display the results.

The data obtained from the sensors were used with an Arduino Nano microcontroller to build a data system. As sensor components, the analogue temperature, pH, TDS, and turbidity sensors were connected to the ATMEGA328P. Figure 5 depicts how the system was designed using the EasyEDA software, and the board was powered by 5 V from the battery. The detected water parameters were wirelessly transmitted to the cloud using MySQL.

The system utilized various sensors, including turbidity, TDS, pH, and temperature sensors, which were meticulously calibrated to minimize errors and enhance accuracy. Calibration involves verifying the accuracy of measurements against a standard and may entail adjusting the instruments to ensure alignment with the standard. Since sensor electrodes can drift over time, it is crucial to compensate for these changes during the calibration process by matching the sensors to their current values. The turbidity sensor was tested with 0 NTU to determine the maximum voltage of the sensor. Calibration was performed using a sample of bean green, with an NTU range of 200–600. The amount of light that reaches the photodiode from the infrared LED reduces with increasing turbidity of the solution. Two distinct reference buffer solutions with pH values of 4.0 and 9.0 were used to calibrate the pH sensor. The sensor was then connected to the microcontroller, and the potentiometer on the circuit board was adjusted to match the accurate result of the pH value.

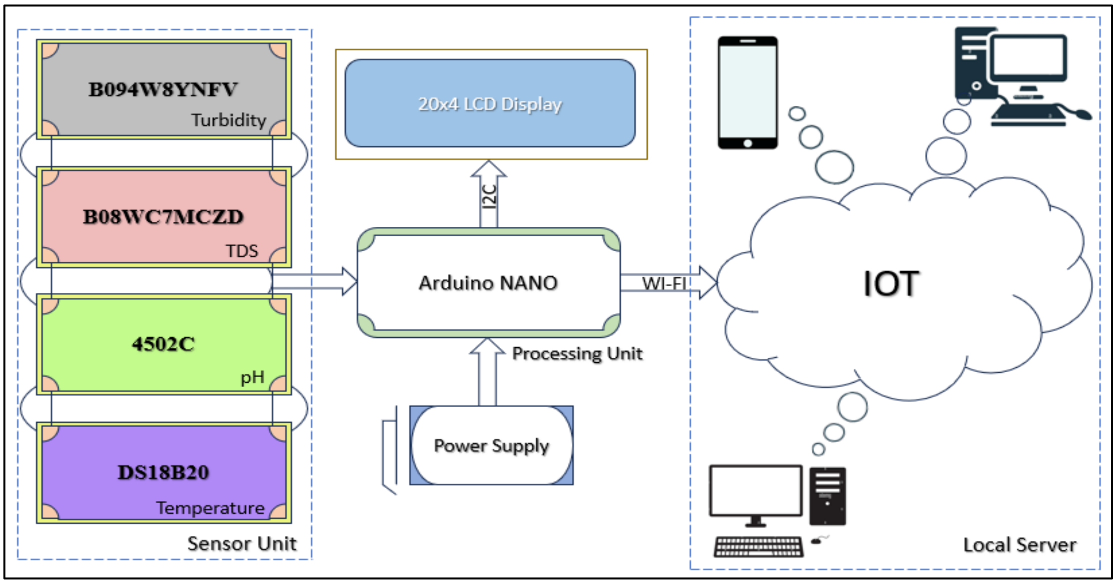


**Figure 1: block diagram**

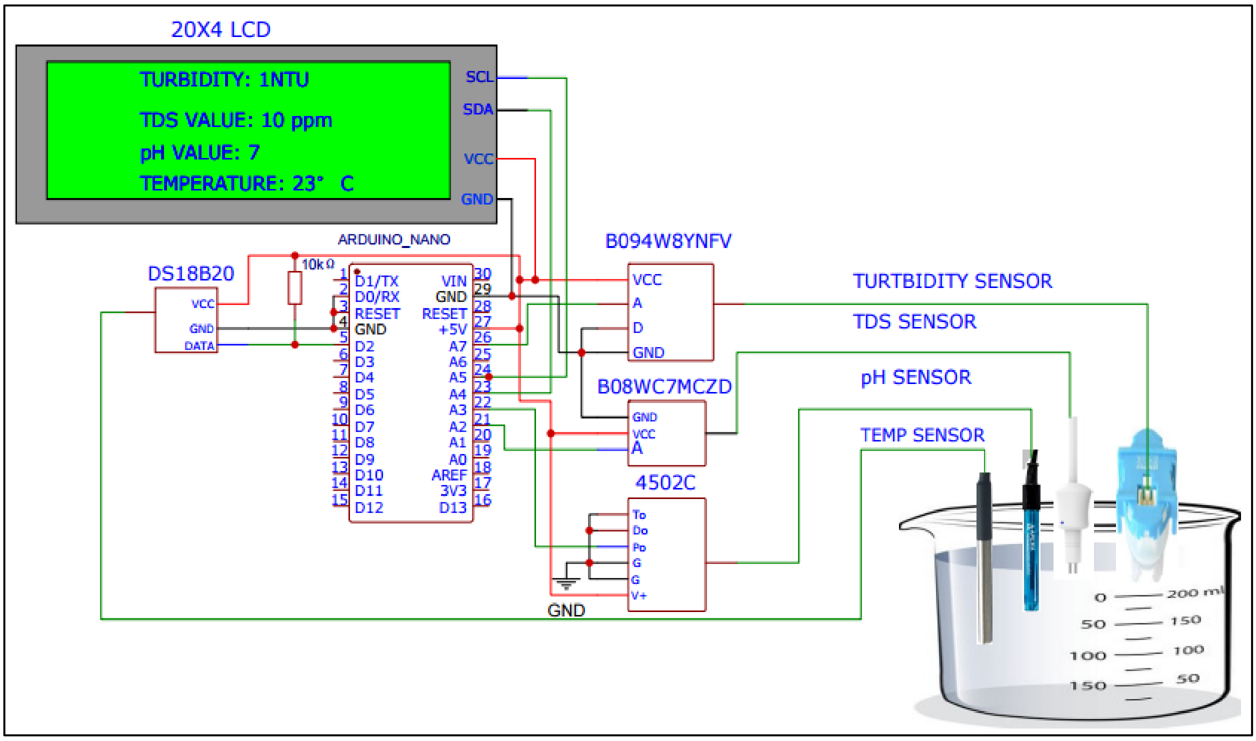


**Figure 2: Schematic diagram of the system**

The TDS sensor can be powered using a voltage of 5V, and connected through the analog input terminal. The conductivity of the solution is measured through the electrodes from the sensor by the microcontroller. The amount of dissolved solids present is represented by a TDS value, which is often expressed in parts per million (ppm). The Arduino 5 V and GND are connected to the board's VCC and GND terminals. The TDS sensor input is then interfaced with the microcontroller. The Maxim Integrated DS18B20 is a multipurpose 1-wire programmable temperature sensor with a single bus port that allows the sensor and the microcontroller to communicate. The two 8-bit storage registers on the DS18B20 sensor, designated storage 0 and 1, store temperature readings. Temperature complements are stored in Storage 0 while the temperature itself, together with its sign, is stored in Storage 1. These characteristics support the DS18B20 sensor's reliability and adaptability in various temperature-related applications. The data pin is connected to VCC through a 10k resistor as a pull-up resistor for the temperature sensor because the DS18B20 temperature sensor has a high impedance. This work measures water parameters and transmits the information to the database, where it is visualized in real-time. Fig. 2 depicts the schematic diagram of the system.

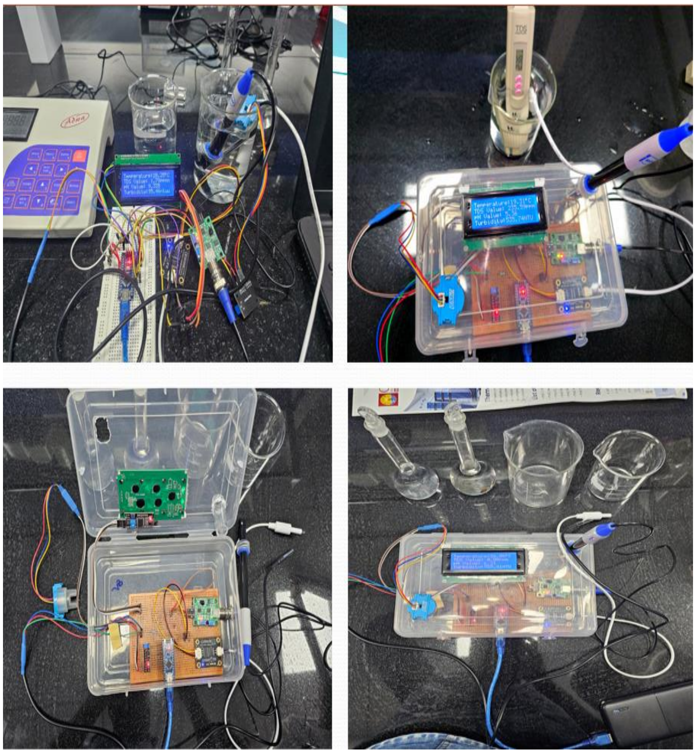

**Figure 3: Designed a system for testing and calibration**

**Software Implementation**

The Arduino microcontroller was programmed using the Arduino Integrated Development Environment (IDE) on a Windows operating system. C++ and Java were the programming languages utilized to program the Arduino Nano microcontroller. This assignment involves receiving and storing sensor data. The necessary void setup and void loop routines are defined, pins on the Arduino are initialized, and libraries for the sensors and Wi-Fi module are included in the IDE.

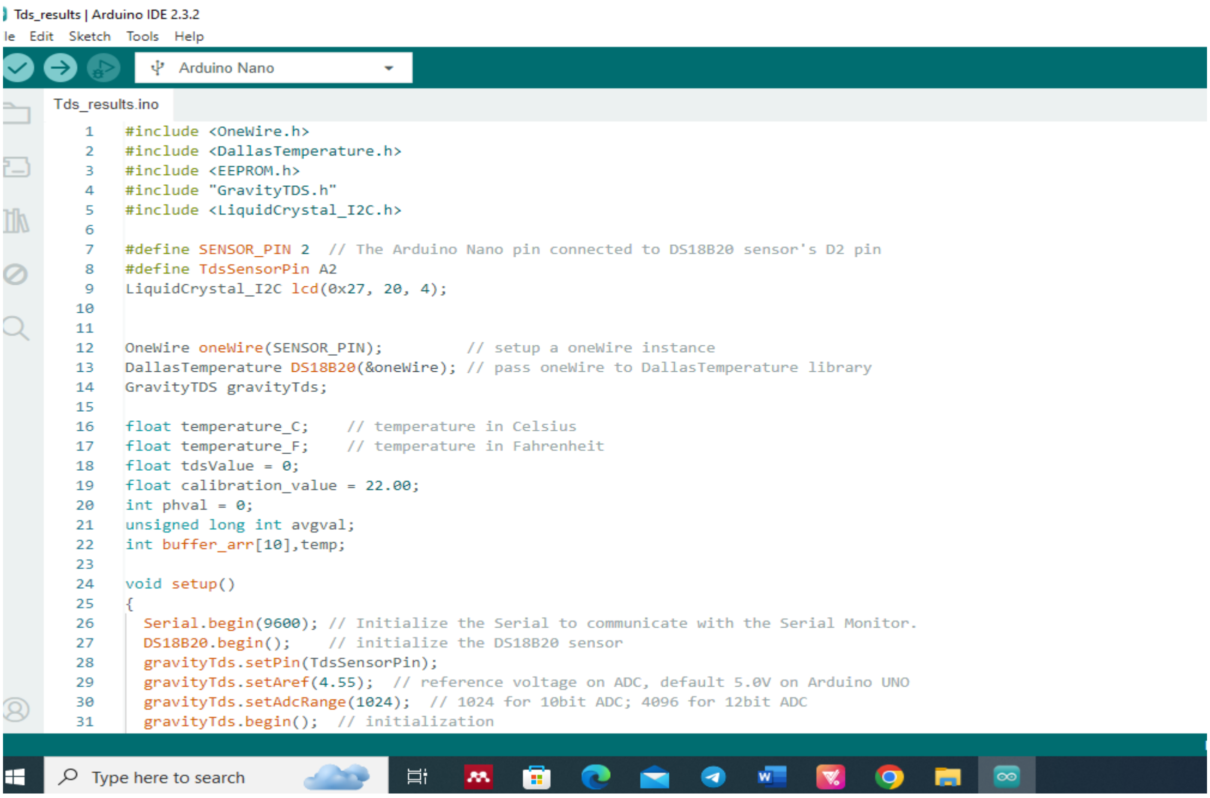


**Figure 4 Arduino IDE**

**MySQL**

The data must be stored to fortify the measured data set from the sensors before the results are displayed on a web server. The MySQL (Structured Query Language) database system is utilized within the selected system to store this information in tabular format. Relational tables are made easier by the open-source MySQL database management system, which Makes it possible to create dynamic databases as shown in Figure 5.

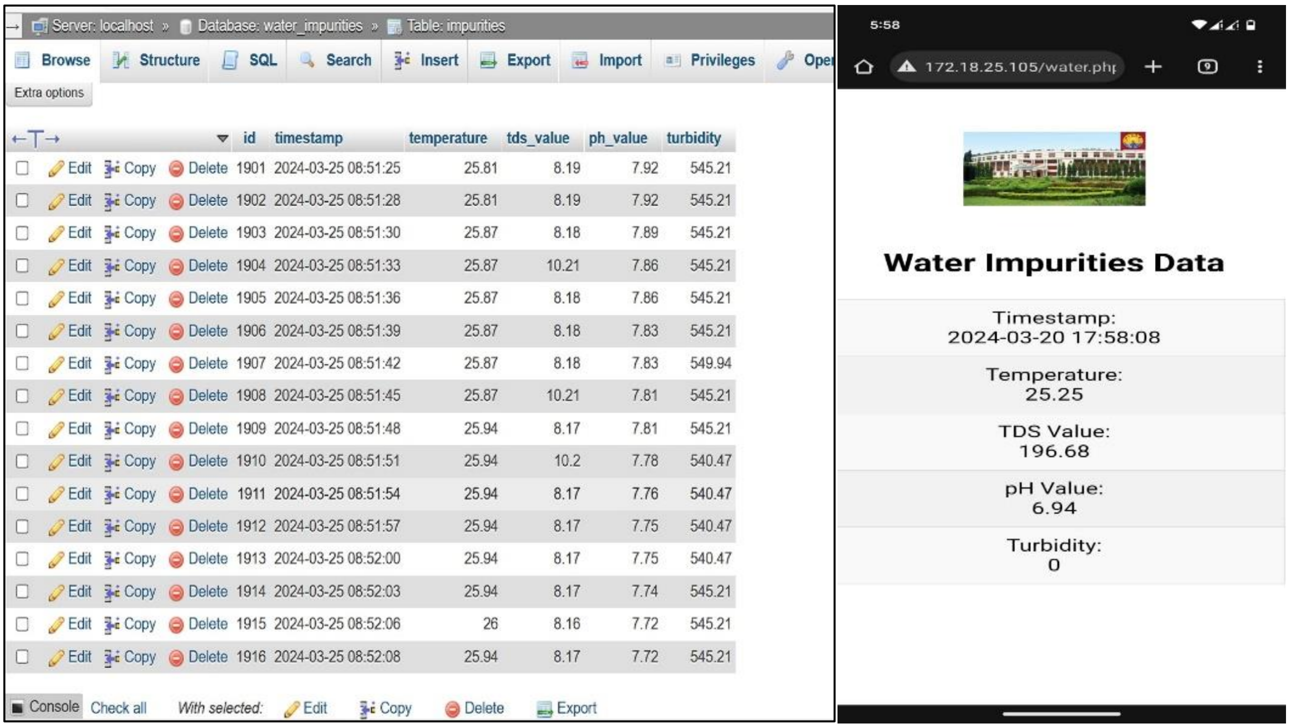


**Figure 5. Storage data in the webpage**

## RESULTS AND DISCUSSION

The result of the designed system was used to monitor the water quality of Sewage and borehole water samples. The measured parameters include temperature, pH, Turbidity (NTU), and total dissolved solids (TDS). The results obtained from the designed device (DD) were compared with the standard device to assess the accuracy and reliability of the designed system.

**Table 1: Average values of physicochemical parameters for Sokoto metropolis sewage water compared to the values obtained from the standard device (SD)**

| Time (hour) | Temperature ($^0$C) | SD (pH) | DD (pH) | SD (NTU) | DD (NTU) | SD (TDS) | DD (TDS) |
|---|---|---|---|---|---|---|---|
| 1 | 23.45 | 7.00 | 7.00 | 2.3 | 2.4 | 314.9 | 312.9 |
| 2 | 24.30 | 6.99 | 7.01 | 2.2 | 2.3 | 30.4 | 321.4 |
| 3 | 25.4 | 7.08 | 7.09 | 2.2 | 2.4 | 322.2 | 323.1 |
| 4 | 26.4 | 7.11 | 7.13 | 2.4 | 2.4 | 324 | 323.3 |
| 5 | 24.61 | 7.12 | 7.15 | 2.5 | 2.5 | 324 | 324.1 |
| 6 | 24.70 | 7.14 | 7.13 | 2.6 | 2.6 | 324 | 325.1 |
| 7 | 25.34 | 7.13 | 7.14 | 2.6 | 2.5 | 323.3 | 324.2 |

The average values of the physicochemical parameters of the Sokoto metropolis sewage water are presented in Table 1. The temperature values ranged from 23.45$^0$C °C to 26.4 $^0$C, which indicated moderate thermal variation within the water samples studied. The pH values measured by the standard device (SD) ranged from 6.99 to 7.14, while the designed device recorded values are between 7.00 and 7.15. The results obtained were in agreement with the values from the standard device, which demonstrated the capability of the designed system for the accurate measurement of pH in sewage water. The turbidity values ranged from 2.2 NTU to 2.6 NTU using the SD, while the DD recorded values are between 2.3 NTU and 2.6 NTU. These results indicated slightly elevated turbidity, which was due to suspended particles and organic matter present in the sewage water. The TDS values obtained from the SD ranged from 314.9 ppm to 324.0 ppm; the minimal difference between each measurement confirmed the consistency and reliability of the system.

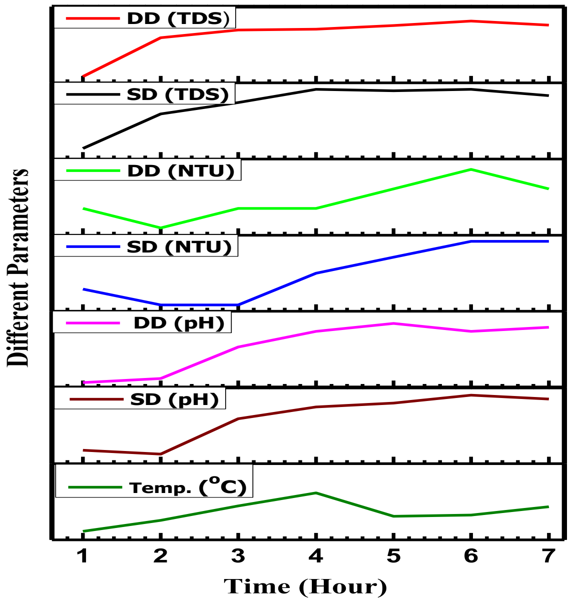


**Figure 6: Average values of physicochemical parameters for Sokoto metropolis sewage water compared to the values obtained from the standard device (SD)**

**Table 2: Average values of physicochemical parameters for Sokoto metropolis borehole water compared to the values obtained from the standard device (SD)**

| Time (hour) | Temperature ($^0$C) | SD (pH) | DD (pH) | SD (NTU) | DD (NTU) | SD (TDS) | DD (TDS) |
|---|---|---|---|---|---|---|---|
| 1 | 33.45 | 6.36 | 6.36 | 0.3 | 0.2 | 521.2 | 521.2 |
| 2 | 32.30 | 6.60 | 6.61 | 0.3 | 0.2 | 522.1 | 522.3 |
| 3 | 31.23 | 6.67 | 6.66 | 0.4 | 0.3 | 521.9 | 521.2 |
| 4 | 30.50 | 6.72 | 6.75 | 0.4 | 0.4 | 524.0 | 523.3 |
| 5 | 32.61 | 6.79 | 6.80 | 0.4 | 0.4 | 524.4 | 524.2 |
| 6 | 30.70 | 6.65 | 6.67 | 0.4 | 0.4 | 524.1 | 524.4 |
| 7 | 31.34 | 6.66 | 6.68 | 0.2 | 0.3 | 523.3 | 523.2 |

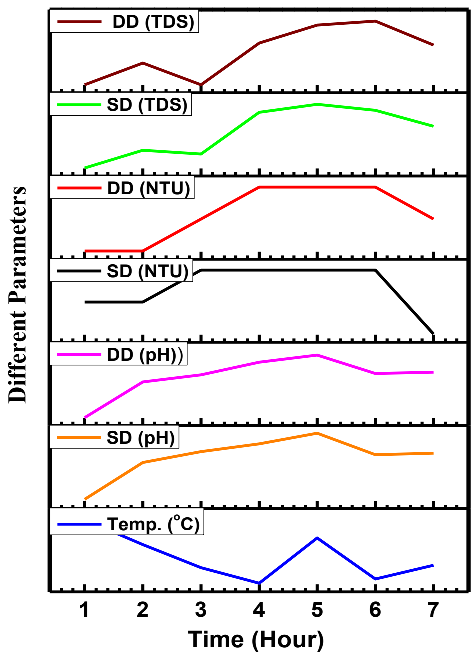


**Figure 7. Average values of physicochemical parameters for Sokoto metropolis borehole water compared to the values obtained from the standard device (SD)**

The average values of the physicochemical parameters of the Sokoto metropolis borehole water are presented in Table 2. The temperature values ranged from 30.50 $^0$C to 33.45 $^0$C. The pH values obtained from the standard device ranged from 6.36 to 6.79, while the designed device measured pH values between 6.36 to 6.80. These values indicated that the borehole water was slightly acidic. The turbidity values ranged from 0.2 NTU to 0.4 NTU for both devices. This confirms that the borehole water is relatively clear and contains minimal suspended solids. The TDS values obtained from the standard device ranged from 521.2 ppm to 524.4 ppm, while the values obtained from the designed device ranged from 521.2 ppm to 524.4 ppm, which indicated that the result was in agreement with values obtained from the standard device. For borehole water, the low turbidity values confirm good physical water quality, while the slightly acidic pH values are common in groundwater due to dissolved carbon dioxide and mineral interactions.

## CONCLUSION

The designed of an embedded system for water quality measurement has been developed and tested. The results obtained by the designed system and correlations to the standard device on the following parameters, pH, turbidity, temperature, and total dissolved solids (TDS) have indicated high levels of effective performance, precision, and reliability of the system. Therefore, this has been proven to be a reliable method of assessing and measuring water quality through the utilization of various water property sensors. This form of assessment is flexible and less expensive because sensors could easily be substituted, along with the required changes in the software to draw data of other parameters in water. The sensors can assess the different required parameters and send the data to the receiving/monitoring device through the implementation of real-time monitoring systems. Further research will look into integrating more sensors for the assessment of electrical conductivity (EC), oxidation-reduction potential (ORP), and total suspended solids (TSS) in water.

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