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Original research article

Prototype system for turbidity and TDS measurement of refill drinking water using Arduino microcontroller

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ABSTRACT

Access to clean drinking water is critical, yet monitoring its quality in refill depots, especially in resource-limited areas, remains a challenge due to costly equipment and limited laboratory access. This work develops an Arduino Uno microcontroller-based prototype of a refill drinking water quality monitoring system based on turbidity and Total Dissolved Solids (TDS) sensors. An LED indicator serves as a visual warning and an LCD module shows real-time measurement results in the system. Five water samples from different depots underwent tests against standard Turbidity Meter and TDS Meter measuring tools. The TDS sensor fit for water quality monitoring since it displayed good performance with a low error of 0.32%–4.02% and high linearity to dissolved substance levels. Whereas the turbidity sensor is more suited for water with moderate to high turbidity, it has limited accuracy, particularly in water with low turbidity (< 5 NTU), with an error of 17%–72%. Particularly in places with limited access to labs and the Internet, this system is expected to be a sensible and affordable solution for independent refill drinking water quality monitoring. Additional development is advised to add IoT integration for remote monitoring, data storage tools, and sensitivity enhancement of the turbidity sensor.

1. Introduction

Clean and safe drinking water is a fundamental necessity essential for maintaining public health [1, 2]. As the population increases and awareness of the importance of water quality increases, the demand for drinking water that meets health standards has also increased. One alternative that is widely chosen by the community is the refill drinking water depot service because it is considered more practical and economical. This service allows consumers to obtain ready-to-drink drinking water without having to go through an additional boiling or filtering

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process at home [3]. While refill drinking water depot services offer convenience, some business units have not fully applied water quality processing and monitoring techniques compliant with accepted standards [4]. Certain depots are known to overlook safety and sanitation issues, so increasing the risk of disease spreads from consumption of water that does not satisfy standards. Consumers must thus be armed with the tools and knowledge necessary to evaluate the drinking water quality they intake.

The Indonesian government has set drinking water quality standards through the Regulation of the Minister of Health of the Republic of Indonesia Number 492/MENKES/PER/IV/2010, which requires drinking water to meet mandatory and additional parameters, both in terms of physics, chemistry, microbiology, and radioactivity [5]. Two important parameters that are indicators of water quality in general are turbidity and total dissolved solids (TDS) [6-10]. High turbidity levels can indicate the presence of suspended particles in the water that have the potential to carry harmful microorganisms [11-15]. Meanwhile, TDS values that exceed the threshold indicate the presence of dissolved substances such as minerals or metal compounds that can be harmful to health if consumed in the long term [16-19].

Microcontroller-based technology has been widely developed for automatic, efficient, and affordable water quality monitoring. Microcontrollers such as Arduino allow integration with various sensors to measure water quality parameters such as pH, temperature, turbidity, and TDS in real time [20-22]. The use of Arduino as a monitoring system platform has advantages in terms of cost, flexibility in programming, and ease of assembly and implementation [23].

The purpose of this project is to use the Arduino Uno microcontroller to design and build a prototype of a turbidity and TDS measurement system for refillable drinking water. This system uses an Arduino-integrated TDS sensor and a turbidity sensor. It also has an LCD module to show the measurement results. This device is made to be used independently in refillable water depots, particularly in places with poor internet connectivity or lab testing facilities. It is hoped that this system will make the process of monitoring water quality easier and more affordable, which will help to improve public health standards and allow for independent drinking water quality monitoring.

2. Literature review

Measuring the quality of refilled drinking water is an important aspect of ensuring the safety of public consumption. Monitoring the quality of refilled drinking water is crucial to ensure that the water consumed meets health standards. Several studies have developed an effective and affordable Arduino microcontroller-based water quality monitoring system [24]. Wong et al. designed an Arduino-based drinking water quality detection tool that measures pH, TDS, temperature, and turbidity parameters [25]. This tool uses a pH sensor, TDS sensor, temperature sensor, and turbidity sensor integrated with Arduino Uno. The test results show that this tool can detect water quality with good accuracy, making it an effective solution for monitoring drinking water quality. Axiotidis et al. developed a drinking water quality measuring tool with parameters of pH, temperature, turbidity level, and total dissolved solids using Arduino [26]. This tool uses a PT1000 sensor for temperature, a pH sensor, a photodiode sensor and infrared LED for turbidity, and a conductivity sensor for TDS.

These studies show that the use of an Arduino microcontroller in a refill drinking water quality monitoring system can produce a tool that is accurate, affordable, and easy to implement. In this study, the author developed a prototype of a turbidity and TDS measurement system for refilling drinking water using an Arduino Uno, equipped with turbidity and TDS sensors, and an LCD. This system is designed for use in drinking water depots with limited internet connections so that it can help ensure the quality of water that is safe for public consumption.

3. Material and method

3.1. Functional approach

This study develops a prototype of turbidity and total dissolved solids (TDS) measurement system in refillable drinking water using an Arduino Uno microcontroller. This system uses a turbidity sensor, and a TDS sensor integrated with Arduino and equipped with an LCD to display the measurement results directly. This system is designed as a simple, affordable, and independent solution from an internet connection, making it suitable for use in small and medium-scale refillable drinking water depots. This prototype system aims to detect the quality of refill water based on physical and chemical parameters, namely turbidity levels and dissolved substance concentrations. Arduino Uno functions as the main processing unit that reads data from two types of sensors:

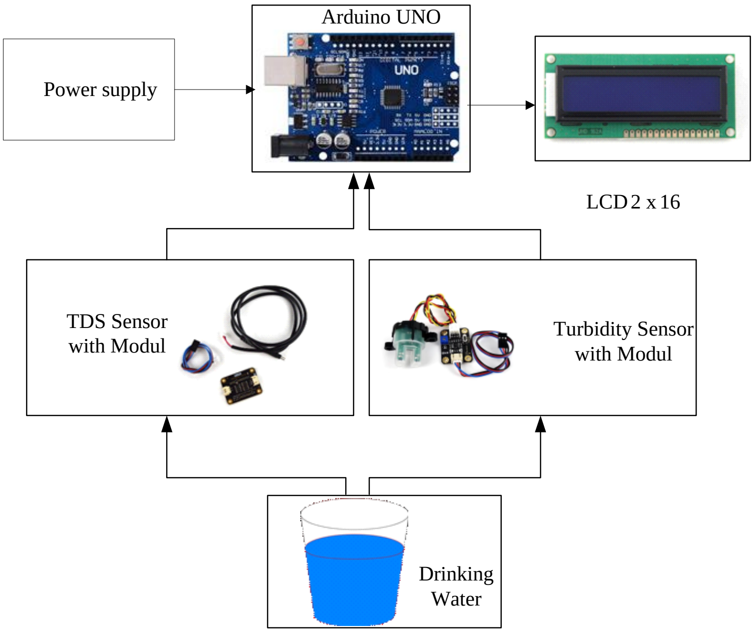

Fig. 1. Block diagram of turbidity and TDS measurement system.

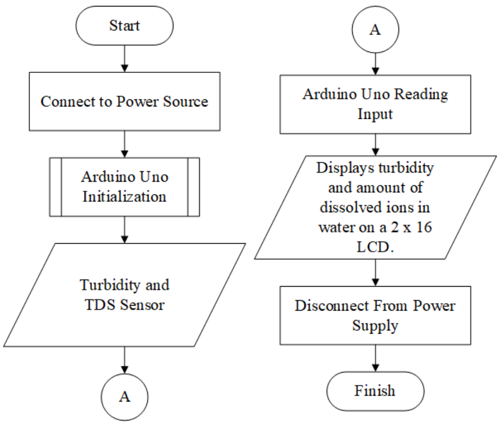

Fig. 2. Flowchart of turbidity and TDS measurement system program.

(1) A turbidity sensor that measures the clarity of water by detecting the intensity of light reflected from suspended particles.
(2) Total Dissolved Solids (TDS) sensor, which detects the number of dissolved ions in water to indicate the purity of the water.

The sensor reading results are displayed via a 16x2 LCD module that is directly connected to the Arduino. If the measured value exceeds the threshold specified in Permenkes No. 492 of 2010, the system can provide an LED indicator signal as a visual warning that the water is not suitable for consumption. The system block diagram is shown in Fig. 1, which includes three main parts: input (turbidity sensor and TDS sensor), process (data processing by Arduino Uno), and output (LCD indicators).

3.2. Structural approach

The hardware is designed modularly with a focus on efficiency and ease of installation. The main components of the system include:

(1) Arduino Uno: Sensor data control and processing center.
(2) Turbidity Sensor: Uses photometric principles to detect suspended particles.
(3) TDS Sensor: Measures water conductivity converted into TDS values (ppm).
(4) 16x2 LCD: Displays measurement results in real-time.
(5) Indicator LED: Provides a warning signal if the value exceeds the safe threshold.

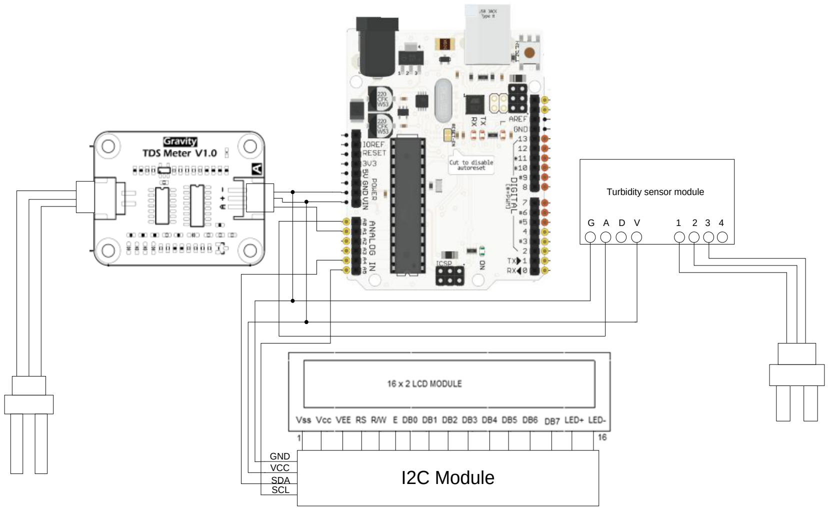

Fig. 3. Entire circuit system.

Fig. 2 illustrates the process flow starting from sensor initialization, data reading, threshold checking to displaying results. Arduino periodically monitors water parameters, then presents information to users instantly. Measurement data can also be recorded manually or continued to the development of an automatic recording system based on external storage such as SD cards or serial communication to a computer.

3.3. Prototype manufacturing

The system prototype (see Fig. 3) was assembled using an Arduino Uno board, a breadboard for temporary connections, and a transparent acrylic casing to protect the circuit from water splashes. Initial testing was conducted in the laboratory using water samples with varying levels of turbidity and TDS (e.g., tap water, refilled water, well water, and bottled mineral water). After the system was successfully tested in a controlled environment, the prototype was tested at one of the refills drinking water depots as a real case study. The purpose of this testing was to evaluate:

(1) Sensor accuracy compared to standard measuring instruments (if available).
(2) Stability to read changes in ambient temperature and lighting.
(3) System response to water conditions that do not meet health standards.

Turbidity and total dissolved substance (TDS) sensors are the two types of sensors used in this study's water quality measurement system. Each sensor type is coupled with a unique sensor module. To make effective use of the pins on the Arduino Uno microcontroller, this system also has a 2x16 LCD connected via the I2C interface. The probe sensor and the sensor module are the two primary parts of the turbidity sensor SKU: SEN0189. There are two sockets on this module: one for the probe sensor and another for the microcontroller. Here's how to connect the sensor to the Arduino Uno:

(1) The GND pin on the sensor module is connected to the Ground (GND) pin on the Arduino.
(2) The V pin on the sensor module is connected to the 5V pin on the Arduino as a voltage source.
(3) The A pin (analog output) on the sensor module is connected to the A0 pin on the Arduino to read the analog signal from the sensor.

TDS Sensor SKU: SEN0244 is also equipped with a sensor module that has four pins, namely a connection to the TDS probe, as well as GND, Analog, and VCC pins for communication with the microcontroller. The connectivity of the TDS sensor to the Arduino Uno is described as follows:

(1) The Analog pin on the TDS sensor module is connected to the A1 pin on the Arduino to read the analog signal.
(2) The GND pin is connected to the Ground (GND) of the Arduino.
(3) The VCC pin is connected to the 5V pin of the Arduino.

To reduce the number of digital pins on the Arduino and provide screen brightness control, all 16 pins of the 2x16 LCD are connected to the I2C module. The four output pins of the I2C module are connected as follows:

(1) The GND pin on the I2C is connected to the Ground (GND) of the Arduino.
(2) The VCC pin on the I2C is connected to the 5V pin of the Arduino.
(3) The SDA pin on the I2C is connected to the A4 pin of the Arduino.
(4) The SCL pin on the I2C is connected to the A5 pin of the Arduino.

The system is simpler to construct, test, and maintain since all component connections are made using conventional jumper wires that are modularly attached on the breadboard and sensor terminals.

4. Results and discussion

This section presents the results of testing and analysis of the refill drinking water quality monitoring system developed using a turbidity sensor and a Total Dissolved Solids (TDS) sensor based on an Arduino microcontroller. Testing was carried out to evaluate sensor accuracy, system reliability, and the suitability of the device to drinking water quality standards based on turbidity and TDS parameters. Before being applied to refill drinking water samples, each sensor was first tested with various types of reference samples to measure the sensor's response to variations in the physical and chemical characteristics of the water. After going through the functional verification stage, the system was then used to measure five refilled drinking water samples obtained from different depots. The measurement results were compared with standard measuring instruments (Turbidity Meter and TDS Meter) to identify the level of accuracy and measurement error.

The analysis of the results is presented in the following sections, starting from testing the turbidity sensor, TDS sensor, and data collection on refilled drinking water, to evaluating the suitability of the overall system to the practical needs of water quality monitoring.

4.1. Turbidity sensor output test

Testing of turbidity sensors was done to assess how well they performed and responded to changes in turbidity levels in a variety of water samples with various optical properties. The test samples included different concentrations of suspended particles and were made up of clear water, tea water, and coffee water, which respectively indicated high and low clarity levels of water. An Arduino Uno microcontroller was connected to the turbidity sensor, which was tested by progressively submerging it in each sample. A monitoring device was used to record the sensor's electrical voltage output, which was then shown as a graph in **Fig. 4**.

Based on the data presented in **Fig. 4**, it can be observed that the highest voltage output value is achieved in clear water samples, indicating low light scattering intensity due to minimal suspended particles. In contrast, the voltage output value decreases gradually in tea water samples and more significantly in coffee water, reflecting increased turbidity due to higher particle concentrations. These results indicate an inverse relationship between the water turbidity level and the sensor output voltage value, which is consistent with the working principle of a light scattering photodetection-based turbidity sensor. When the scattering intensity increases along with the increasing number of particles in the medium, the light reaching the photodetector decreases, resulting in a decrease in the voltage value. Thus, these test results prove that the turbidity sensor used can provide a functionally appropriate response to variations in turbidity levels in the test water samples.

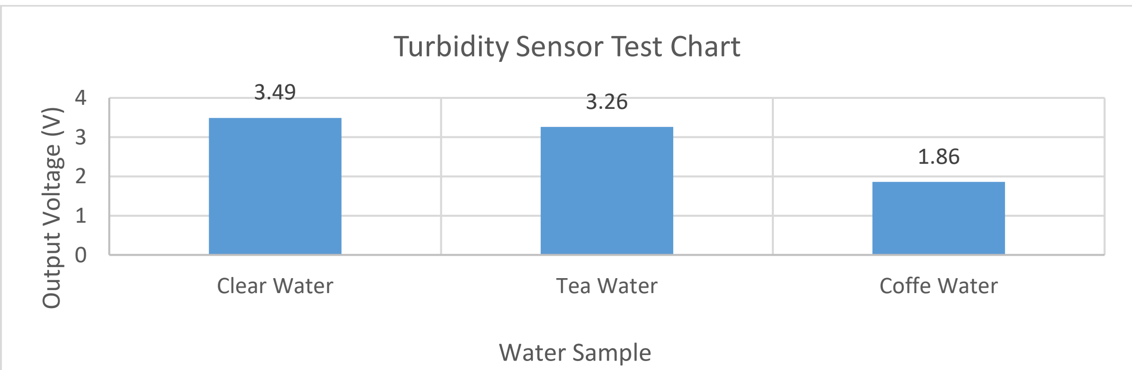

Fig. 4. Turbidity sensor output results graph on various water samples.

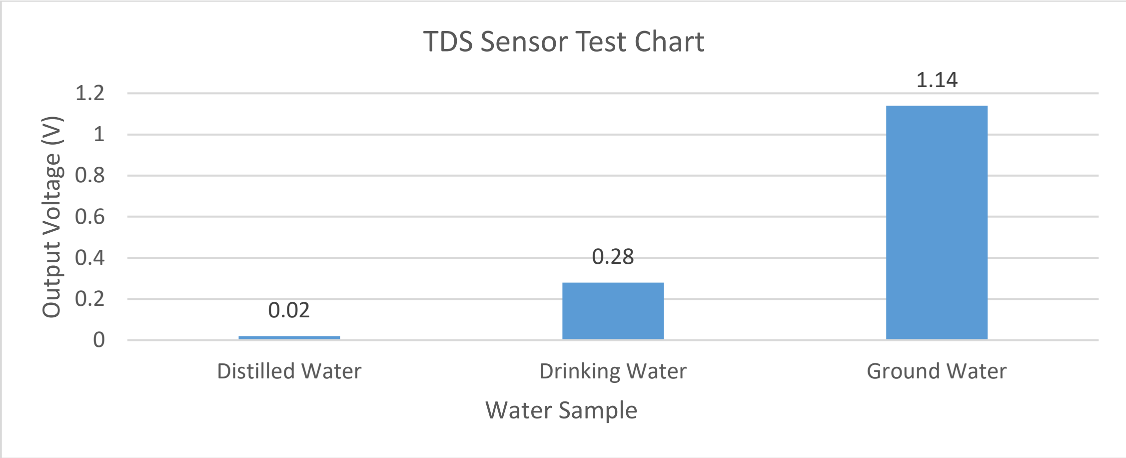

Fig. 5. Graph of TDS sensor output results on various water samples.

4.2. TDS sensor output test

Testing of the Total Dissolved Solids (TDS) sensor was done to see how well it could identify and measure the number of dissolved solids in different kinds of water samples [6, 27]. Based on variations in the properties of their dissolved material content, three different sample types were chosen: groundwater (high TDS), distilled water (as an example of water with extremely low TDS), and bottled drinking water (mid-TDS). The TDS sensor was alternatively dipped into each sample and was linked to a microcontroller system. Once the output value stabilized, data gathering was completed, and **Fig. 5** displays the measurement findings as a graph illustration.

Based on the graph in **Fig. 5**, it can be observed that the lowest output voltage value is produced by distilled water, which theoretically has a dissolved solids concentration close to zero. Meanwhile, bottled drinking water shows a higher output voltage value, and groundwater produces the highest value, reflecting the largest dissolved solids content. The pattern of increasing output voltage in line with increasing TDS levels indicates that the TDS sensor operates consistently against variations in electrical conductivity caused by the presence of dissolved ions in water. In the context of electrochemical measurements, the output voltage of the TDS sensor is directly correlated with the conductivity level of the solution, which in turn becomes a quantitative indicator of the number of dissolved solids. Therefore, these test results indicate that the TDS sensor used has adequate sensitivity and accuracy in measuring water quality parameters based on TDS levels.

4.3. Turbidity Sensor Sampling Data

A prototype of the planned water quality measuring system was used for data collection following preliminary testing to make sure the sensor function was operating as intended. Five replenishment drinking water samples that were collected from five separate depots were tested. To measure each sample in turn, a microcontroller was attached to both the turbidity and Total Dissolved Solids (TDS) sensors. It should be mentioned that the turbidity sensor's physical design has restrictions due to the probe's non-waterproof top. In order to keep water out of delicate electrical components, the sensor immersion process was done with extreme caution. Turbidity level measurement is done by two methods, namely using a turbidity sensor integrated into the system and a standard Turbidity Meter tool as a reference. The measurement results are summarized in Table 1. The measurement findings are the average of 25 data acquisitions for each sample to improve accuracy and reduce measurement variability. A graph that better illustrates the data is shown in Fig. 6.

Table 1
Turbidity measurement results using sensors and turbidity meters

Drinking water sample	Turbidity meter (NTU)	Turbidity sensor (NTU)	Error measurement
Depot X	0.54	0.15	72%
Wan Cell	0.34	0.15	56%
Depot Yudi	0.18	0.15	17%
Medina Cell	0.21	0.15	29%
Depot Y	0.12	0.15	25%

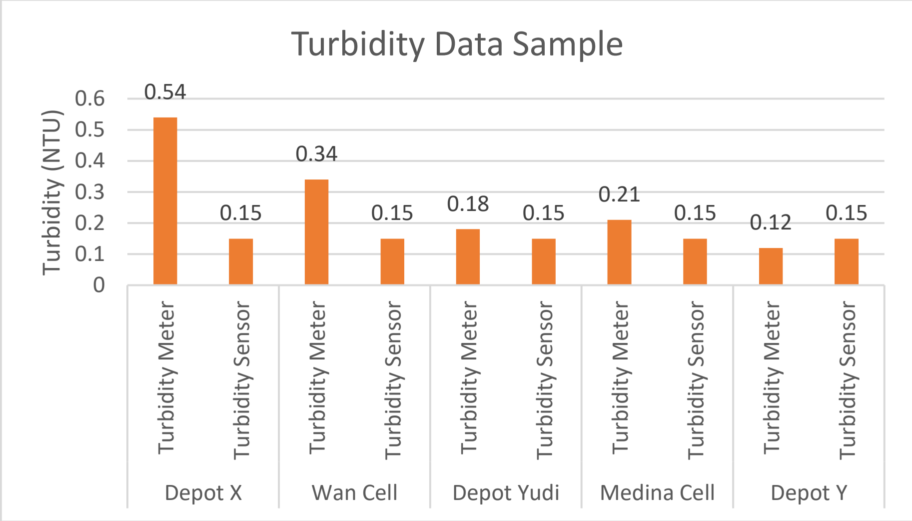

Fig. 6. Comparison graph of turbidity measurement results.

Table 2
Measurement results of drinking water samples using TDS sensor and TDS meter

Drinking water Sample	TDS sensor (ppm)	TDS meter (ppm)	Error measurement
Depot X	74.43	75	0.76%
Wan Cell	155.63	157	0.87%
Depot Yudi	73.73	74	0.36%
Medina Cell	44.15	46	4.02%
Depot Y	152.49	152	0.32%

Based on data analysis, there is a significant difference in value between the measurement results of the turbidity sensor and the Turbidity Meter. The percentage of measurement error ranges from 17% to 72%, which indicates a large deviation, especially in samples with low turbidity levels. This is due to the limited sensitivity of the turbidity sensor used, where the sensor is unable to detect turbidity values below 5 NTU accurately. This sensor works on the principle of detecting light scattering by suspended particles in water, but in very clear water, the intensity of the light scattering produced is very low and difficult to detect by the sensor. Thus, the turbidity sensor in this prototype is more suitable for application to water with moderate to high turbidity levels, such as river water, lakes, or wastewater, compared to drinking water, which has very low turbidity.

4.4. TDS sensor sampling data

Total Dissolved Solids (TDS) levels in replenished drinking water were measured to assess the precision and functionality of the TDS sensor built into the system prototype. Five samples of water were collected from various replenishment depots. The sensor was submerged in each sample until the value stabilized to calculate the average value. Twenty-five times, this procedure was carried out. However, the measurement was also taken with a standard TDS meter. The average measurement results are displayed in Table 2.

Visualization of TDS measurement results can be seen in Figure 9. The graph shows a comparison between the average value of dissolved solids (TDS) measurements obtained from the TDS sensor and the standard TDS Meter tool on five refill drinking water samples. The value trend shown by the sensor is in line with the standard tool, which indicates the consistency of sensor performance in detecting variations in dissolved substance concentration between samples. The relatively small difference in value between the two measuring devices indicates that the sensor has a high level of accuracy and precision, so it can be relied on as the main component in a microcontroller-based water quality monitoring system.

The TDS sensor performed exceptionally well in identifying the number of dissolved solids in replenished drinking water, according to the measurement findings. With error values ranging from 0.32 to 4.02%, the measurement error rate was very low. Samples from the Wan Cell depot had the highest TDS value, measuring 155.63 ppm, while samples from Medina Cell had the lowest, measuring 44.15 ppm. These findings generally show that the TDS sensor is compatible with common comparator devices and has high linearity to dissolved solids levels.

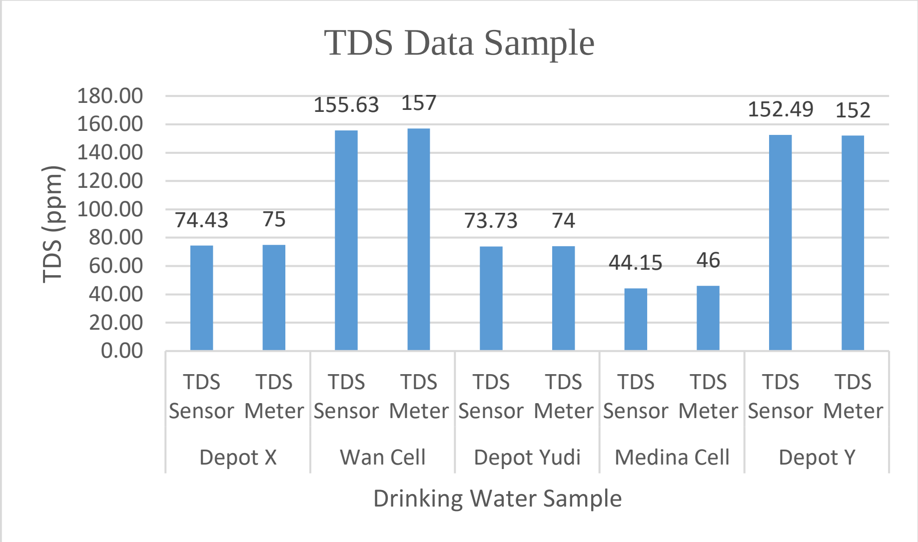

Fig. 7. Comparison graph of TDS measurement results.

These results corroborate the claim that TDS sensors, particularly for TDS parameters, may be employed successfully in refill drinking water quality monitoring systems. The low error coefficient value, which shows that the deviation of the sensor results from the standard tool is within allowable bounds for real-world applications, further supports the sensor's dependability. The TDS sensor showed high accuracy with measurement error below 5% in all samples, indicating that this sensor is very feasible and reliable for use in refill drinking water quality monitoring systems. Turbidity Sensor, on the other hand, shows inadequate performance in the low turbidity range (< 5 NTU). The high measurement error rate (up to > 70% in some samples) indicates that this sensor is not recommended for testing drinking water with low turbidity. However, this sensor still has potential for use in water measurement applications with high turbidity levels, such as river water, lakes, or wastewater [18, 28-30].

5. Conclusions

This study successfully designed and developed a prototype of a refill drinking water quality measurement system based on the Arduino Uno microcontroller, by utilizing a turbidity sensor and a Total Dissolved Solids (TDS) sensor. This system is equipped with a 16x2 LCD display and LED indicator as a visual information media that makes it easy for users to monitor water quality directly. The test results on five refilled drinking water samples from various depots showed that the TDS sensor worked well, indicated by a very low measurement error rate, ranging from 0.32% to 4.02% compared to standard measuring instruments. This shows that the TDS sensor is quite accurate and reliable in measuring the content of dissolved substances in water.

Despite its usefulness, the turbidity sensor exhibits limited accuracy when measuring very low turbidity levels, such as those typically found in refilled drinking water. Measurement errors associated with this sensor range from 17% to 72%, indicating that it is more reliable in detecting moderate to high turbidity levels in more turbid water sources. Nevertheless, the developed prototype system presents significant potential for autonomous water quality monitoring, especially in areas with limited access to laboratory facilities and internet infrastructure. It's simple and modular architecture, combined with the use of cost-effective components, facilitates implementation, making this system particularly advantageous for small and medium-sized companies operating in the refilled drinking water sector.

This system also successfully displays real-time measurement results via LCD and provides visual warnings via LED indicators, which greatly assist users in quickly assessing whether the water is suitable for consumption or not. As a follow-up, it is recommended to replace the turbidity sensor with a type that has higher sensitivity so that the accuracy of measurements on clear water can be improved. In addition, the addition of data storage features or integration with external storage devices such as SD cards can expand the functionality of the system, especially in recording measurement history.

Further development can also include integration with an Internet of Things (IoT)-based system so that water quality monitoring can be carried out remotely and more efficiently. With these improvements, this system has the potential to become an effective, affordable, and useful tool in supporting the supervision of the quality of refilled drinking water in order to maintain public health.

Declaration statement

Irma Saraswati was responsible for the overall research design, supervision, and final review of the manuscript. **Romi Wiryadinata** and **Heri Haryanto** contributed to data analysis and literature review. **Ahmad Ramadhani** and **Nauval Franata** contributed to writing – review & editing, literature review, validation, and manuscript writing. **Muchtar Ali Setyo Yudono** and **Ratu Verlaili Erlindriyani** contributed to writing – original draft, visualization, methodology, and formal analysis. **Ganda Himawan**, a final-year undergraduate student, assisted in laboratory work, sample preparation, and data collection under the supervision of the lead researcher.

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Disclosure statement

The authors declare no conflicts of interest.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

AI Usage Statement

Generative AI and AI-assisted tools were used to enhance the language and readability of this manuscript. The authors have reviewed and revised all AI-generated content to ensure its accuracy and alignment with the research. The authors remain fully responsible for the work's scientific content, conclusions, and integrity, and disclose the use of AI to ensure transparency and adherence to publisher guidelines.

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