JRA 15484

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IMPROVED DESIGN AND ACCURACY OF REAL-TIME WATER QUALITY AND FILTERING SYSTEMS FOR APPLICATION IN IOT-BASED AQUACULTURE

ABSTRACT

Maintaining optimal water quality is essential in fish farming, as fluctuations in key parameters, such as pH, turbidity, and dissolved compounds, can lead to stress, disease, and even fish death. This study aimed to design and develop an Internet of Things (IoT)-based water quality monitoring and filtration system that can operate in real-time to support the sustainability of aquaculture. This system integrated pH, turbidity, total dissolved solids (TDS), and ultrasonic sensors with Arduino Uno and ESP32 microcontrollers. Sensor data was transmitted in real-time to an Android application, which displayed it on an LCD, allowing users to monitor water quality and receive alerts when parameters deviated from optimal thresholds. The test results demonstrated a high level of sensor accuracy, specifically 96.51% for pH, 98.19% for TDS, and 97.03% for turbidity, as determined through comparisons with laboratory equipment, commercial devices, and manual measurements. The effectiveness of the filtration system was also proven to be significant: turbidity was reduced by an average of 58.87%, TDS decreased by 26.80%, and pH values became more stable within the optimal range for aquaculture with an improvement of 7.3%. This system was able to maintain the variation of the main water quality parameters within the ranges for raw and drinking water stipulated in Indonesian Government Regulation No. 22 of 2021 and Regulation of the Minister of Health No. 492 of 2010. This improved design is arguably more efficient than conventional methods because it reduces the need for labor and provides early warning of changes in water quality.

KEYWORDS: automatic monitoring; fish farming; IoT; water filtration; water quality

ABSTRAK: Desain dan Konstruksi Alat Penyaringan dan Pemantauan Kualitas Air pada Sistem Budidaya Perikanan Berbasis IoT

Menjaga kualitas air yang optimal sangat penting dalam budidaya ikan, karena fluktuasi parameter utama seperti pH, kekeruhan, dan kandungan zat terlarut dapat menyebabkan stres, penyakit, hingga kematian pada ikan. Penelitian ini bertujuan untuk merancang dan mengembangkan sistem pemantauan dan penyaringan kualitas air berbasis internet of things (IoT) yang dapat beroperasi secara real-time untuk mendukung keberlanjutan akuakultur. Sistem ini mengintegrasikan sensor pH, turbiditas, total dissolved solids (TDS), dan sensor ultrasonik dengan mikrokontroler Arduino Uno dan ESP32. Data sensor ditransmisikan secara real-time ke aplikasi Android dan ditampilkan melalui LCD, memungkinkan pengguna memantau kualitas air dan menerima peringatan ketika parameter menyimpang dari ambang batas optimal. Hasil pengujian menunjukkan tingkat akurasi sensor yang tinggi, yaitu 96,51% untuk pH, 98,19% untuk TDS, dan 97,03% untuk kekeruhan, berdasarkan perbandingan dengan alat laboratorium, perangkat komersial, dan pengukuran manual. Efektivitas sistem filtrasi juga terbukti signifikan: kekeruhan berkurang rata-rata 58,87%, TDS menurun sebesar 26,80%, dan nilai pH menjadi lebih stabil dalam kisaran optimal untuk akuakultur dengan perbaikan sebesar 7.3%. Sistem ini telah memenuhi ketentuan Peraturan Pemerintah No. 22 Tahun 2021 dan Peraturan Menteri Kesehatan No. 492 Tahun 2010 untuk kualitas air baku dan minum. Sistem ini terbukti lebih efisien dibanding metode konvensional karena mengurangi kebutuhan tenaga kerja dan memberikan peringatan dini terhadap perubahan kualitas air.

KATA KUNCI: budidaya perikanan; filtrasi air; IoT; kualitas air; pemantauan otomatis

INTRODUCTION

Aquaculture has a crucial role in supporting global food security and contributes significantly to national economic growth (Adhawati & Nuryanti, 2021; Cokrowati *et al*., 2023). One of the key factors determining success in aquaculture operations is maintaining optimal water quality conditions, which in turn determine the health, growth, and productivity of cultured fish (Hakim *et al*., 2023). Poor water quality, resulting from the accumulation of organic waste or physical and chemical imbalances that alter temperature, pH, and dissolved oxygen (DO), can lead to stress in fish, increase the risk of disease outbreaks, and even result in mass mortality. Therefore, effective and efficient water quality management is one of the primary requirements in a successful fish farming operation.

Conventional methods in water quality management generally rely on mechanical filtration to reduce residual feed, feces, and other dissolved organic matter (Ariadi *et al*., 2023; Boyd & McNevin, 2021). However, the system still relies heavily on manual monitoring, which is prone to delays in decision-making and the waste of resources. As technology advances, the use of the Internet of Things (IoT) in aquaculture and water management systems has evolved as a solution for automatic and real-time water quality monitoring. This system allows the integration of various sensors—such as temperature, pH, DO, TDS, and turbidity—connected to a cloud platform to send data directly to user devices (Arepalli & Naik, 2024; Desnanjaya & Nugraha, 2022; Desnanjaya *et al*., 2024; Xu *et al*., 2023; Yuniarti *et al*., 2021). Unfortunately, most IoT-based systems currently only focus on monitoring functions, without integrating automatic and adaptive water treatment or filtration processes.

Various previous studies have been conducted to develop IoT-based water quality monitoring systems. For example, Lubis & Pulungan (2023) developed a well water quality monitoring system based on pH, turbidity, and temperature sensors using Arduino Uno and NodeMCU ESP8266 connected to the Blynk application. Their system was capable of carrying out real-time monitoring with fairly high accuracy, although the pH sensor has an average error of 2.6% (Lubis & Pulungan, 2023). Hariyadi *et al*. (2020) also developed a pH measuring device for drilled well water using a liquid pH sensor; however, they did not develop the technology for further water treatment. Zaenurrohman *et al*. (2023) developed an automatic water purification system utilizing repeated filtration with activated carbon media, manganese sand, and cotton, along with a monitoring system based on turbidity and ultrasonic sensors. This system successfully increased water clarity by up to 47.56% and can be controlled via the Blynk application (Zaenurrohman *et al*., 2023). Latukolan & Wastumirad (2024) developed a more complex river water quality monitoring system that accurately measured temperature, pH, salinity, and turbidity, and displayed the data in real-time via an LCD, the Blynk application, and a Telegram Bot. A similar study conducted by Bareta (2021) in ornamental fish aquariums also demonstrated that a monitoring system based on pH, temperature, and humidity sensors provided accurate data after calibration.

Although the previously mentioned studies demonstrate advances in water monitoring technology, a significant gap remains, specifically the lack of a system that fully integrates monitoring with automatic filtration, particularly for aquaculture applications. Therefore, this study takes further steps by designing an IoT-based water quality monitoring and filtration system equipped with pH, turbidity, TDS, and ultrasonic sensors, and utilizing an Android application called WaMoS as a control and monitoring medium for aquaculture applications. The primary objective of this innovation was to provide an integrated solution for maintaining the optimum condition of rearing water for fish farming. It is expected that, in the long term, this system can be further developed with artificial intelligence (AI) to predict changes in water quality and take corrective actions automatically. Thus, this research not only makes theoretical contributions to the field of water monitoring and treatment technology, but also has a practical impact in supporting the sustainability of safe and efficient access to clean water for the broader community.

MATERIALS AND METHODS

The research was conducted in a biofloc aquaculture system facility owned by the Institute of Business and Technology Indonesia, Bali. The biofloc system was selected based on its characteristics, which require high efficiency in water quality management.

Data collection was conducted systematically and standardized to obtain accurate and relevant information in support of the research objectives. The data collected were used to test previously formulated hypotheses. This study used primary and secondary data collection methods. Primary data were obtained through direct observation of water conditions in the biofloc system, including changes in water color, clarity, and the presence of suspended particles. In addition, measurements of water quality parameters such as temperature, pH, total dissolved solids (TDS), and turbidity were carried out using IoT-based sensors controlled by the Arduino Uno microcontroller and NodeMCU ESP32.

The sensors used in this system included a turbidity sensor to measure water turbidity, a pH-4502C sensor to measure water pH, and a TDS sensor to detect the total amount of dissolved substances in water. In addition to sensory and instrumental observations, interviews were also conducted with fish farmers to determine the obstacles in water quality management and the effectiveness of the filtration technology applied.

The system design consisted of a combination of hardware and software components. The Arduino Uno and ESP32 microcontrollers served as the central processing units for sensor data and IoT connectivity. The system was also equipped with a solenoid valve and water pump, each controlled through 4-channel relays, allowing the system to automatically regulate water flow based on sensor readings. For power requirements, a 12V 20A power supply was used, the voltage of which was then adjusted using a buck converter to be compatible with other components. Measured results were displayed via a 16x2 LCD and also sent to an Android application in real-time, and stored in a cloud-based database for further analysis. System programming was done using the C language for microcontrollers and Python for data integration and IoT interfaces.

System testing was conducted in several stages to evaluate the effectiveness of the filtration device and the water quality monitoring system. The first stage involved sensor calibration using a standard solution to ensure the accuracy of data readings, which were then compared with conventional measuring instruments for verification. The second stage involved filtration performance testing, where water quality parameters were measured before and after passing through the filtration system to assess efficiency based on reduced turbidity and TDS levels, as well as improvements in overall water quality. Furthermore, IoT integration testing was conducted to ensure that sensor data could be transmitted and displayed in real-time within the Android application, as well as to verify the system's automatic response to changes in water parameters.

Filtration System

Water filtration technology is a crucial method for providing clean water, particular in areas with limited access to modern water treatment systems (Sasmoko *et al.*, 2019; Sofarini *et al.*, 2022; Utari *et al.*, 2022). This process works by separating solid particles and various contaminants from water through a series of layers of filter media arranged in a tiered manner. Each layer of media has a specific function that complements the other to produce cleaner water. The filtration system used in this study consisted of five layers: cotton, activated carbon, silica sand, zeolite, and gravel. The first layer was cotton, which functions as an initial filter to capture coarse dirt and sediment in water. With high porosity, cotton can retain solid particles on its surface while allowing water to flow through it (Iskandar *et al*., 2022; Zahra *et al*., 2023). The second layer was activated carbon, which is carbon that has been activated through chemical treatment or high temperature heating to increase its surface area and absorption capacity. Activated carbon is effective in absorbing various organic and inorganic compounds, including heavy metal ions, dyes, unpleasant odors, and hazardous chemicals (Purwanti *et al*., 2021; Zaenurrohman *et al*., 2023). The third layer was silica sand, which is composed of silica crystals (SiO_2). This media functions to filter fine particles and helps precipitate small dirt particlesthereby increasing water clarity (Utari *et al*., 2022). The fourth layer consisted of zeolite, an aluminosilicate mineral with a microporous structure. Zeolite has an excellent ability to absorb heavy metals, pesticides, and detergents, as well as remove microbiological contaminants such as bacteria and viruses (Onyutha *et al*., 2024; Velarde *et al*., 2023). The last layer was gravel, which not only acts as a filtering medium for large particles but also functions to support the overall structure of the filter layer and create space for stable water flow. The combination of these five media forms a simple yet highly effective filtration system for removing various types of contaminants from water. Several studies support the effectiveness of this media combination, including showing that the use of activated carbon and silica sand can reduce TDS and increase water clarity. The integration of zeolite has been shown to accelerate the removal of heavy metals and pathogenic microorganisms. With readily available materials, low cost, and high effectiveness, this filtration system can be the ideal solution for providing clean water, especially in areas where people do not yet have access to advanced water treatment technology.

The filtration system in IoT-based fish farming utilized two types of filters with varying sizes and paths to optimize the water filtration process. The first filter was larger and served as the initial stage of filtration, where large particles, such as leftover feed and fish waste, were filtered first. The second filter, which is smaller, acted as a secondary filter to ensure that only small particles remained before the water was returned to the cultivation system. Both filters were designed with special paths that allow water to flow efficiently and optimally, making the filtration process more effective and producing clean, high-quality water.

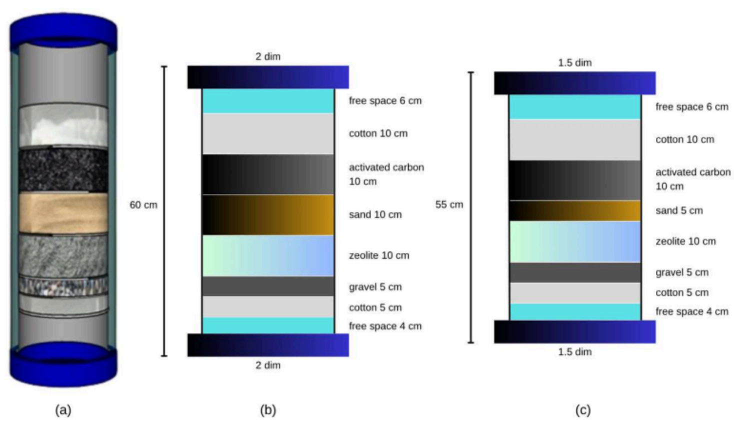


Figure 1. Filter design. (a) Display of contents in the filter; (b) Filter design 1; and (c) Filter design 2

In this research, two water filtration units with different sizes and paths were successfully implemented to maximize the effectiveness of the filtration process. The strategy of using two filters with different characteristics aimed to create a layered filtration system, which not only filters large particles but also ensures that the water produced has a high level of clarity and quality. The first filter has a larger dimension and functions as an initial filtration stage. In this filter, large particles contained in the water were filtered first, thereby significantly reducing the workload on the second filter. Meanwhile, the second filter is smaller and is designed for a further filtration process, where small particles that pass through the first filter will be filtered more finely to produce clean water.

In the system implementation, the first filter tool, as shown in Figures 1 and 1a, had a length of 60 cm with a 2-inch diameter pipe. This filter consisted of several layers of media arranged vertically to support the gradual filtration process. The first layer had a 6 cm free space that serves as the initial distribution space for water before it enters the filter media. Next, the water passed through a 10 cm-thick cotton layer that played a role in filtering large particles down to small ones. Underneath the cotton layer, a 1 kg layer of activated carbon was placed to absorb organic matter, unpleasant odors, and bad tastes in the water. After activated carbon, the water was flowed through a 10 cm thick layer of sand to hold mud deposits or suspended particles. The next layer was a 10 cm-thick zeolite media that functions to reduce the levels of magnesium ions and other heavy metals in the water. Then, the water passes through a 5 cm thick layer of gravel that helps smooth the flow of water and prevents blockages due to deposits. The final filter was a 5 cm-thick layer of cotton that functions to capture fine particles that are still left over from the previous layer. The second filter, shown in Figure 1b, was 55 cm long with a pipe diameter of 1.5 inches. Although smaller in size, the arrangement of the filter media was relatively similar to that of the first filter, with the only difference was the thickness of the sand layer (5 cm).

The selection of filter media, including cotton, activated carbon, silica sand, zeolite, and gravel, is carefully considered to create a multi-layered filtration system with multiple barriers that target different types and sizes of contaminants, ensuring thorough water purification. Cotton acts as the primary mechanical filter, capturing larger suspended solids and particulate matter. Its fibrous structure effectively traps debris, preventing clogging of subsequent media layers and protecting the activated carbon and finer filter layers from overloading. Activated carbon plays a crucial role in adsorbing dissolved organic compounds, chlorine, and unpleasant odors and tastes that cannot be removed by mechanical filtration alone. Its high surface area and porous nature make it highly effective in improving water quality by reducing chemical contaminants and enhancing the sensory qualities of the water. Silica sand provides further mechanical filtration by capturing smaller particles and sediments that pass through the cotton and activated carbon layers. The granular nature of the sand supports the development of biofilms, which can aid in the biodegradation of certain pollutants, further enhancing water purification. Zeolite is used for its ion exchange properties, specifically its ability to adsorb ammonia, heavy metals (such as magnesium and other harmful ions), and other dissolved inorganic contaminants. This makes zeolite important in reducing toxic substances that can have a detrimental effect on aquatic life and water quality. The gravel serves primarily as a support layer, stabilizing the filter media above it and ensuring an even distribution and smooth flow of water throughout the filter. The gravel also helps prevent clogging by providing sufficient space for water to pass through, thereby maintaining filter efficiency over time. Together, these media form a synergistic filtration system, where each layer targets specific contaminants and protects the next layer, resulting in a gradual, effective, and reliable process of water purification. This combination is based on well-established filtration principles and is supported by numerous studies demonstrating the individual and collective efficacy of these materials in aquaculture and water treatment applications.

Reservoir Design

The water reservoir in this system is used to store water before and after the filtration process. Each reservoir has a capacity of 50 L and serves as a temporary storage container, allowing the filtration process to run more smoothly and efficiently (Figure 2). The water that enters the filtration system comes from the initial reservoir. After going through the filtration process, clean water is flowed to the final reservoir before being reused in fish farming. To ensure that the water supply remains available, this system is equipped with an automatic filling mechanism. If the water level in the tank drops to a certain limit, the system will automatically refill the water until it reaches the optimal capacity. Thus, the sustainability of the water cycle in fisheries cultivation is maintained without the need for excessive manual intervention.

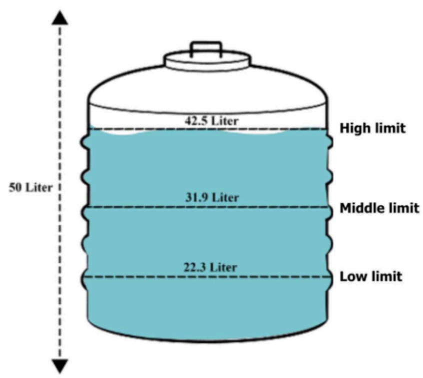


Figure 2. Reservoir design of Internet of Things (IoT)-based water quality monitoring system

System Analysis

System analysis is essential to support system performance, ensuring that the system created aligns with the needs of the aquaculture system. This study employed system analysis to ensure the achievement of the system's main objectives, specifically increasing the efficiency of water quality management. Two systems' requirements were identified, including functional and non-functional requirements. The hardware components were identified in the functional needs analysis, while the non-functional needs analysis assessed the needs for external factors supporting the tool's operation. These needs included hardware, software, and user needs (brainware) components. Based on system analyses, designing and building water quality filtration and monitoring tools for IoT-based aquaculture requires different hardware and software components, as listed in Tables 1 and 2. The descriptions of the functional needs analysis are as follows:

1. Using Arduino Uno and NodeMCU ESP32 modules as the system processing center and as a link between the tool and the application via WiFi connectivity.
2. Using a turbidity sensor to measure the level of water turbidity in the cultivation system.
3. Using a PH-4502C sensor to measure the pH level of the water to ensure optimal conditions for the fish.
4. Using a TDS sensor to measure the amount of dissolved solids in the water.
5. Displaying real-time water quality monitoring results via an Android-based application.
6. Using a water pump to flow the filtered water back into the cultivation pond.

Table 1. Tools and materials of the Internet of Things (IoT)-based water quality monitoring system

Tools and materials	***Quantity***
½" PVC pipe	3 m
2" PVC pipe	1 m
1 ½" PVC pipe	1 m
L ½" pipe	12 pcs
Pipe glue	1 pcs
Cotton	2 packs
Activated carbon	2 kg

Tools and materials	Quantity
Sand	1 kg
Zeolite	1 kg
Gravel	1 kg
Laptop	1 unit

Table 2. Electronic Components of the Internet of Things (IoT)-based water quality monitoring system

Electronic component	*Quantity*
Arduino Uno	1 pcs
NodeMCU ESP32	1 pcs
Ultrasonic sensors	1 pcs
Turbidity sensors	1 pcs
PH-4502C sensor	1 pcs
TDS sensor	1 pcs
Selenoid valve	2 pcs
Water pump	2 pcs
4-channel relay	1 pcs
LCD 16x2	1 pcs
Power supply 12V 20A	1 pcs
Buck converter	1 pcs

The software used in this study comprises various applications and programs that support the monitoring system and sensor data processing. This system uses C and Python-based programming to integrate sensors with microcontrollers. Monitoring data is displayed through an Android-based application that allows real-time monitoring and is stored in a cloud database for further analysis.

Block Diagram

A block diagram is one of the most important parts of system design. The diagram is used to understand the overall workflow of the process implemented in the IoT-based aquaculture monitoring and filtration system. Figure 3 illustrates a block diagram of the design for the water monitoring and filtration tool used in the fisheries cultivation system. This system consists of several main components that are interconnected. The Arduino Uno was supplied with voltage by a 12V power supply, which was then reduced to 4.9V using a buck converter. The main sensors used in this system included the Turbidity, PH-4502C, Ultrasonic, and TDS sensors. Arduino Uno is responsible for processing data from these sensors and sending output in real-time to the 16x2 LCD. Meanwhile, NodeMCU ESP32 was used to send measurement results to Android-based applications.

This system is also equipped with actuators that function to maintain the balance of water quality in fisheries cultivation. The solenoid valve is activated when the ultrasonic sensor detects the water level below the specified limit. Additionally, the relay and water pump are activated if the pH-4502C sensor, turbidity sensor, or TDS sensor detects an imbalance in water quality, allowing the filtration system to maintain optimal water parameters.

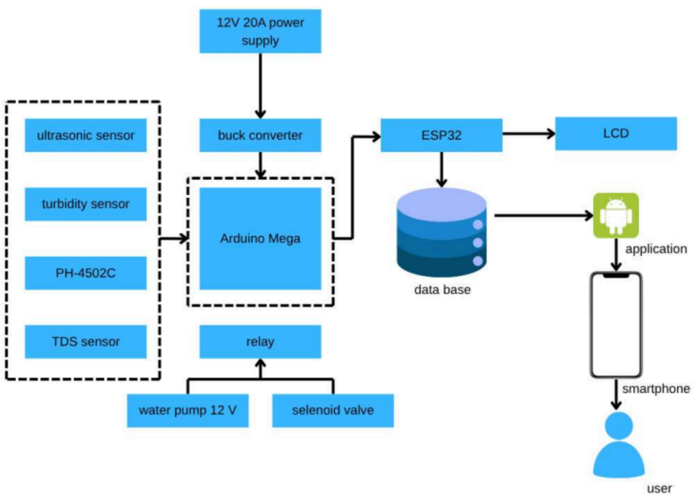


Figure 3. Block diagram of the Internet of Things (IoT)-based water quality monitoring system

Schematic

Figure 4 illustrates the Proteus schematic, which outlines the entire tool, "Design and Construction of Water Quality Filtering and Monitoring Tools in IoT-Based Aquaculture Systems." This schematic illustrates the connections between the pH-4502C, turbidity, TDS, and ultrasonic sensors and the Arduino Uno. In addition, the NodeMCU ESP32 is used to retrieve output data from the Arduino Uno and display the results on an Android-based monitoring application.

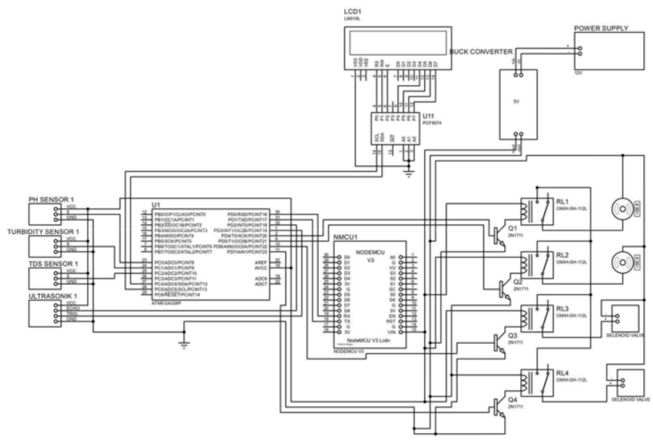


Figure 4. Schematic of the Internet of Things (IoT)-based Aquaculture water quality monitoring system

Measurement of Water Level and Water Quality Parameters

To determine the water level and water quality, several approaches are employed, primarily through sensor-based data acquisition and subsequent computational analysis. The calculations for water level are presented in Equations 1 and 2, while the water quality calculations are detailed in Equation 3. To validate the measurements, this research refers to water quality standards from two main national regulations in Indonesia. First, the Regulation of the Ministry of Health of the Republic of Indonesia No. 492/MENKES/PER/IV/2010, concerning the Requirements for Drinking Water Quality, is used as the benchmark. This regulation sets the maximum allowable limits for various physical and chemical parameters of water, including turbidity, pH, color, odor, taste, and TDS, to ensure water safety and potability (Table 3). Second, to expand the applicability beyond potable water, this research also refers to Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. This regulation establishes Environmental Quality Standards for various classes of surface water. Specifically, Water Class I is used as a reference because it represents the most stringent standard, intended for water sources used as raw water for drinking purposes. Parameters such as temperature deviation (± 3°C from ambient air), turbidity (≤25 NTU), pH (6.0–9.0), TDS (≤1000 mg L^{-1}), as well as allowable concentrations of metals like aluminum (0.2 mg L^{-1}), iron (0.3 mg L^{-1}), manganese (0.4 mg L^{-1}), and copper (2.0 mg L^{-1}), are all regulated under this framework (Menteri Kesehatan Republik Indonesia, 2010; Presiden Republik Indonesia, 2021).

By combining both regulations, this study provides a dual benchmark to evaluate whether the water quality measured by the system aligns with both potable water safety requirements and broader environmental water quality standards. This approach ensures that the developed system is applicable not only in aquaculture but also in environmental monitoring and water resource management contexts.

$$Vb = Kt \times 15\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$Vt = Kt - Vb \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$Ta = \left(\frac{Vt}{Kt}\right) \times Tt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Formula description:

Vb = Volume of reduced water

Vt = Remaining water volume

Kt = Total capacity of the reservoir (L)

Ta = Remaining water height (cm)

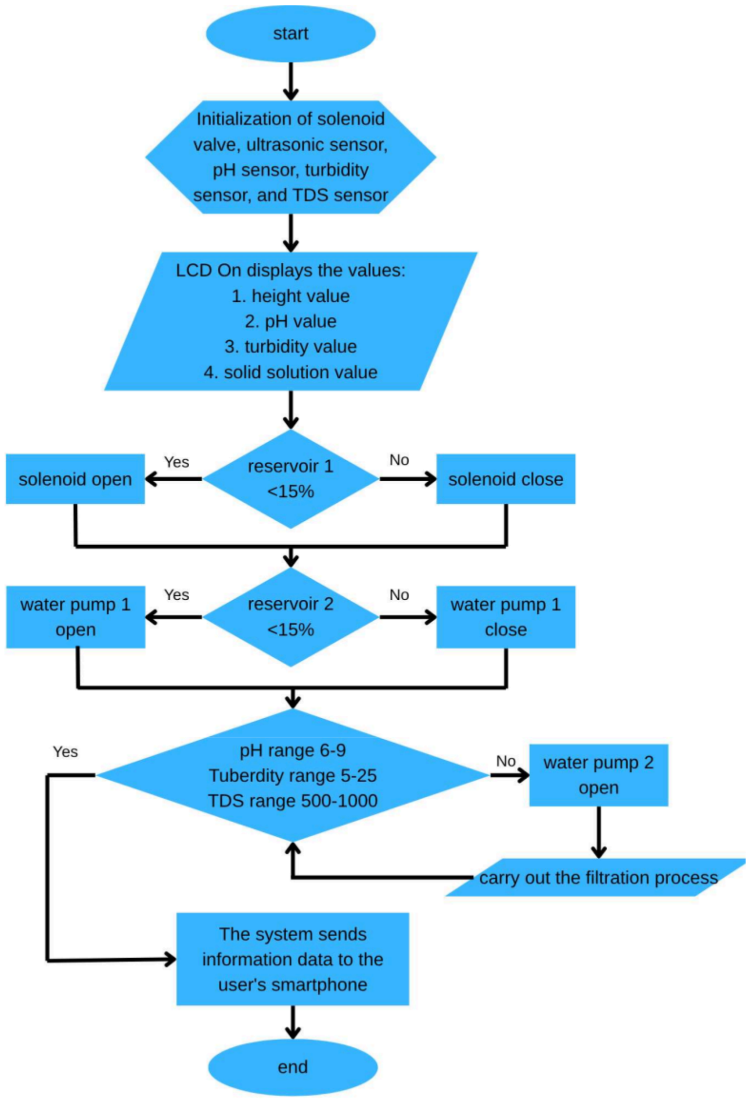
Tt = Total height of the reservoir

Table 3. Water quality parameters based on Minister of Health Regulation No. 492/2010 and PP No. 22/2021 of the Internet of Things (IoT)-based water quality monitoring system

Parameter	Unit	Permenkes 492/2010	PP 22/2021 (Class I)
Physical parameters			
Odor	-	Odorless	Odorless
Color	TCU	15	50
Total dissolved solids (TDS)	mg L^{-1}	500	1000
Turbidity	NTU	5	25
Taste	-	Tasteless	-
Temperature	°C	±3°C from ambient air	±3°C from ambient air
Chemical parameters			
pH	-	6.5-8.5	6.0-9.0
Aluminum (Al)	mg L^{-1}	0.2	0.2
Iron (Fe)	mg L^{-1}	0.3	0.3
Manganese (Mn)	mg L^{-1}	0.4	0.4
Zinc (Zn)	mg L^{-1}	3.0	5.0
Copper (Cu)	mg L^{-1}	2.0	2.0
Ammonia (NH_3-N)	mg L^{-1}	1.5	0.5
Chloride (Cl^-)	mg L^{-1}	250	600
Sulfate (SO_4^{2-})	mg L^{-1}	250	400
Hardness (as $CaCO_3$)	mg L^{-1}	500	-

Flowchart

To describe and simplify the processes and procedures in the filtration system and water quality monitoring, a flowchart (Figure 5) was developed to facilitate an understanding of the system's workflow and how each component interacts in the processing and monitoring of water quality. The first stage is sensor initialization, during which sensor readings are taken alternately. The first sensor to be read is the ultrasonic sensor, followed by the pH-4502C sensor, then the turbidity sensor, and finally the TDS sensor. Each sensor's data is displayed in real-time on the LCD installed in the monitoring system. The ultrasonic sensor is used to detect the water level in the reservoir. If the water level in reservoir 1 is less than 15%, the solenoid valve opens to fill the reservoir with water. Otherwise, the solenoid valve remains closed. A similar process occurs in tank 2, but in this tank, a water pump is used to regulate the water flow. The pH-4502C sensor is designed to detect the pH level of water within a normal range of 6.5-8.0. If the pH value exceeds this limit, the system issues a warning to the monitoring application. The Turbidity sensor is used to measure the turbidity level of water with a normal range of 5-25 NTU. If the turbidity level exceeds the specified limit, the system activates the filtration process. The TDS sensor is used to measure the total dissolved solids in water with a normal range of 300-600 mg L^{-1}. If the TDS value exceeds the limit, the system automatically activates the water pump to channel water into the filter for the filtration process. After the filtration process is complete, the water in the tank is monitored again to ensure that the water quality parameters meet the standard benchmarks. If all parameters have met the standards, the water is considered suitable for reuse in the cultivation system. All data obtained from the sensor will be displayed in real-time on the Android-based application, allowing users to easily monitor water conditions and take action as needed.



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394 Figure 5. Flowchart of Internet of Things (IoT)-based water quality monitoring system

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Overall Design and Placement

This system comprises various hardware and software components designed to operate in an integrated manner, enabling users to monitor water quality in real-time through an Android application (Figure 6). In the developed Android application system, the primary user, referred to as User, has access to monitoring features and historical water quality information. The Use Case Diagram illustrates user interaction with the system. Users can access the main page of the application, which contains the menu options Tank 1, Tank 2, and Monitoring History. Users can view water quality data, including parameters pH, turbidity, TDS, and water level in the tank, in real-time. Additionally, users can access the history page, which stores monitoring data updated every 30 minutes. This system does not allow users to control the device directly; instead, it functions as a monitoring tool, providing warnings if the water quality parameters exceed normal limits.

To store data obtained from the sensors, the system utilizes a database designed using an entity-relationship diagram (ERD). This database consists of two main tables, namely Tandon and Riwayat. The Tandon table is used to store water quality data obtained from the sensors, including Tandon ID, water pH, turbidity, total dissolved solids (TDS), and water level. This data is updated in real-time to provide an overview of water conditions in the cultivation system. Meanwhile, the Riwayat table functions to store historical data on water quality parameters, including Tandon ID, water pH, turbidity, TDS, the time and date of recording, and the water status (suitable or unsuitable). Storing this historical data helps analyze trends in water quality changes over a specific period.

A data flow diagram (DFD) is used to describe the flow of data within a system. The level 0 DFD of this application shows how sensor data is collected and processed to be displayed to the User. The data collection process is carried out using sensors that periodically read water quality parameters, then send the data to the processing system via

Arduino and ESP32 microcontrollers. The data obtained is then stored in a database and displayed on an Android application. During the monitoring process, users can open the application to view water parameters in real-time. If one of the parameters exceeds the specified limit, the system will provide a notification to the User. Historical data can also be accessed for further analysis.

The user interface (UI) is designed to provide an intuitive and easy-to-use display. When the application is first opened, a loading screen will display before entering the main page. The main page features a main menu comprising Tank 1, Tank 2, and Monitoring History. The monitoring page displays water quality data for each tank, including water pH, turbidity, TDS, and water level, which are updated in real time based on sensor readings. The monitoring history page displays a record of changes in water quality based on the data collected. Warning notifications are issued when water quality parameters exceed normal limits, and the data is updated every 30 minutes to provide an overview of the water conditions in the cultivation system.

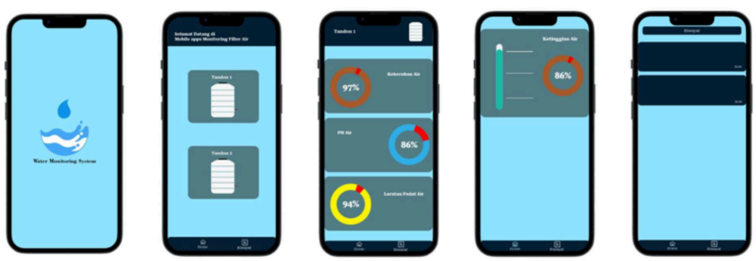

Figure 6. Page view of the user interface of the Internet of Things (IoT)-based water quality monitoring system on a smartphone

The workflow of this sensor-based water quality monitoring and filtration system is divided into several stages. The water used in the system is sourced from a well and stored in a main tank with a capacity of 350 L, located 3.5 m above ground level. This main tank is designed with an automatic filling system that allows water to refill when its volume is below a certain threshold, thus ensuring a stable and efficient water supply during the filtration process.

Furthermore, water from the main tank is channeled to the filtration system through a mechanism controlled by a solenoid valve, which functions as an automatic tap. The first stage of filtration is carried out with the help of Water Pump 1, which pushes water towards Water Filter 1. Water that has passed through the first filter then enters Tank 1, which has a capacity of 50 liters. If the filtration results do not meet quality standards, the water will be reprocessed by Water Pump 2 and channeled to Water Filter 2 for further filtration. The results of this process are then collected in a temporary reservoir, which serves as a medium for reading sensor data before the water is used further.

The entire system is built into one sturdy and compact frame unit, with the main frame measuring 83 cm (width), 61 cm (length), and 120 cm (height). Meanwhile, the system box used to place electronic devices and controls has dimensions of 20 cm (width), 15 cm (length), and 25 cm (height). The integration between the filtration system and the monitoring system makes this device not only effective in purifying water but also capable of providing real-time water quality data that can be used for continuous evaluation and control of water quality.

System Testing Scenario

The system testing stage is carried out to evaluate the performance of the filtration device and the IoT-based water quality monitoring system. This test ensures that the system operates according to design and provides accurate and efficient results. The following are the stages of the test scenario carried out:

1. Arduino Uno and ESP32 testing

In the first stage, a connection test was conducted between the Arduino Uno and the ESP32. The purpose of this test is to ensure that the Arduino Uno can process data from the sensor and send the results to the ESP32, which will then send the data to the Android-based monitoring application. The expected result is that the system can send all sensor data in real-time without interruption. In these sensor tests, the test was conducted for 135 seconds, with data collected every 15 seconds to obtain the results of each test.

2. Sensor testing and calibration

The second stage is testing all sensors used, including the pH-4502C, turbidity, TDS, and ultrasonic sensors. Each sensor is tested and calibrated to ensure that the data produced is accurate and follows the specified standards. The expected result is that the sensor can accurately read water quality parameters. As a comparison tool for the IoT-based water quality monitoring system used in this study, several conventional methods and other tools that have proven their accuracy were also applied. First, conventional laboratory testing was conducted for pH, TDS, and turbidity parameters using standard tools, including digital pH meters, TDS meters, and turbidimeters, with high precision. Second, the measurement results were compared with other commercial water quality monitoring systems that are already available on the market and have a good reputation, such as AquaMonitor and Sensorex. These systems were chosen because they have been widely used in automatic water quality monitoring and are considered to have a high level of accuracy. Third, verification was also carried out through manual measurements using a laboratory kit, which was conducted simultaneously with data collection from the IoT system. The purpose of this step is to validate the data generated by the IoT-based system through comparison with standardized manual methods.

3. Water pump and relay testing

   In the third stage, testing was conducted on the water pump system and the relay, which functions as an automatic switch to activate and deactivate the water flow in the filtration system. The purpose of this test is to ensure that the water pump operates according to the programmed conditions, based on data from the sensor.

4. Testing the effectiveness of filtration

   The fourth stage involves testing the performance of the filtration system by comparing the quality of water before and after it passes through the filter. The parameters measured include turbidity levels, pH, and TDS content. The expected result is that water that has undergone the filtration process has a better quality than before filtration, per water quality standards for fish farming. In this testing process, the system also calculates the level of accuracy and the difference between the sensor readings and the reference values obtained from the standard tool. Two main formulas are used in this test. First, equation 4 is used to calculate the difference. Where Measured is the value obtained from the sensor, and Reference is the reference value from the standard tool used as a comparison.

   Furthermore, to calculate the level of accuracy, equation 5 is used, which shows the percentage of sensor accuracy. The higher the percentage of accuracy, the more precise the sensor reading is to the reference value. With this method, the reliability of the system can be evaluated quantitatively before it is fully integrated into the water monitoring and filtration process. The effectiveness of the filtration tests was evaluated over a 7-day period. From these results, further analysis was conducted by comparing the values before and after filtration, and then adjusted according to references from Permenkes No. 492 of 2010 and PP No. 22 of 2021.

$$\text{Difference} = \text{Measured} - \text{Reference} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

$$Accuracy\ (\%) = (1 - (Difference\ /\ Reference)) \times 100 \ldots\ldots\ldots\ldots 5$$

5. Overall system testing

The final stage is testing the entire system, including the monitoring application, sensor data processing system, and filtration equipment. The purpose of this test is to ensure that all components function in an integrated manner and provide results that comply with the designed specifications. The expected result is that the system can help users accurately monitor water quality and ensure the filtration process runs optimally according to predetermined standards.

RESULTS AND DISCUSSION

This study aimed to design and develop an automatic filtration device and an Internet of Things (IoT)-based water quality monitoring system for use in a fish farming system. The developed system integrates several water quality sensors, namely pH sensors, turbidity sensors, and TDS sensors, which are connected to actuators in the form of water pumps and solenoid valves. These components are controlled automatically and will only be active when the water quality parameters are detected to be outside the safe threshold. Thus, this system can maintain optimal water quality, supporting fish growth.

The sensors used in this system are capable of sending data in real-time to the Android application and displaying it on the LCD screen, allowing users to continuously monitor water conditions with minimal intervention. The sensor test results showed good and accurate performance. The pH sensor recorded values between 6.1 and 6.7 with an accuracy of 96.51%. This range has largely met the water quality standard requirements, according to Minister of Health Regulation (Permenkes) No. 492 of 2010, which stipulates an ideal pH range of 6.5 to 8.5, and Government Regulations (PP) No. 22 of 2021, which stipulates a pH range of 6.0 to 9.0 for class I water. The TDS sensor shows a value between 601 to 690 ppm with an accuracy of 98.19%. This value exceeds the maximum limit of 500 ppm for direct drinking water, as specified in Permenkes No. 492 of 2010. Nonetheless, it is still below the maximum limit of 1000 ppm for raw water, as stated in PP No. 22 of 2021, which is safe for use in fish farming. The turbidity sensor recorded a value between 2.1 and 5.5 NTU (accuracy 97.03%), with a small number of values exceeding the benchmark limit of 5 NTU. However, all values were still below the maximum limit of 25 NTU, as per PP No. 22 of 2021. The explanations of these values are provided in Figures 7 to 12.

The designed filtration system has proven to be effective in improving water quality. After the filtration process, the water turbidity level decreased by 58.87%, the TDS level decreased by an average of 26.80%, and the pH value became more stable with a pH improvement of 7.3%. This demonstrates that the system is capable of maintaining water quality parameters within optimal limits and in compliance with applicable regulations. Additionally, the automatic operation of pumps and solenoid valves ensures the continuous availability of clean water without requiring manual intervention. This system is also considered more efficient than conventional monitoring methods because it can reduce labor requirements, conserve water and energy usage, and provide early warnings of significant changes in water quality.

Although the system has shown positive results, several challenges have been faced during development, particularly related to sensor durability in environments with high organic content, as well as decreased accuracy if the sensor is not regularly calibrated. Therefore, further development is recommended to incorporate additional sensors, such as DO and ammonia sensors, and to implement artificial intelligence (AI) technology to analyze water quality change patterns and provide automatic action recommendations. The use of renewable energy sources, such as solar panels, can also enhance overall energy efficiency. This effort aligns with the concept of the blue economy, which is part of the Indonesian government's policy, particularly the Ministry of Maritime Affairs and Fisheries' efforts to encourage sustainable and environmentally friendly aquaculture practices.

Overall, the IoT-based water quality monitoring and filtration system developed in this study has been proven to maintain water quality parameters within safe limits, following PP No. 22 of 2021, as raw water, and in many cases, also meets the standards of Permenkes No. 492 of 2010 for drinking water. With its broad development potential, this system is highly suitable for application in the modern aquaculture industry, which prioritizes efficiency, reduced use of insecticides, and environmental protection.

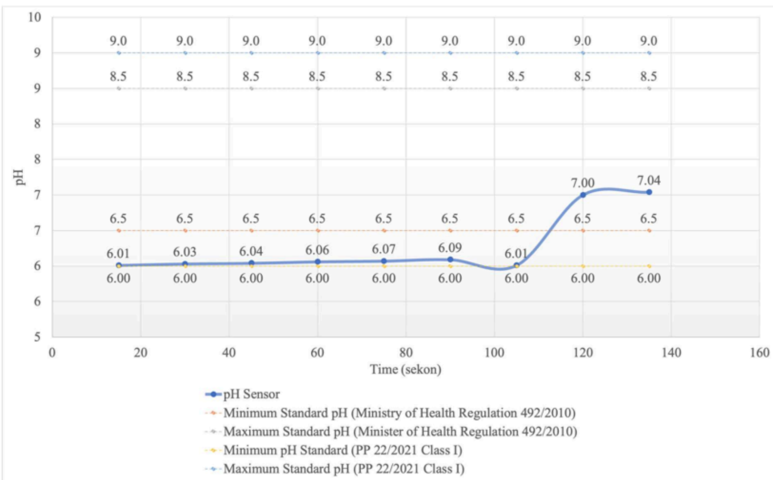

Figure 7. Comparison of pH sensor readings with regulatory standard ranges over time

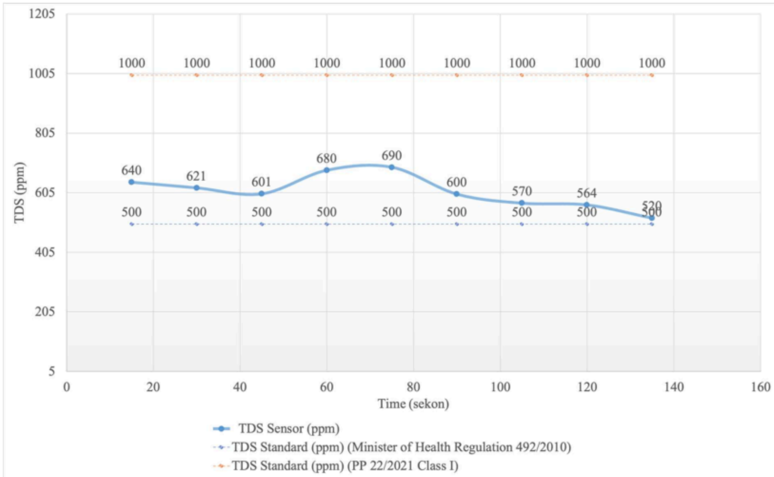

Figure 8. Comparison of total dissolved solids (TDS) sensor readings with regulatory standards over time

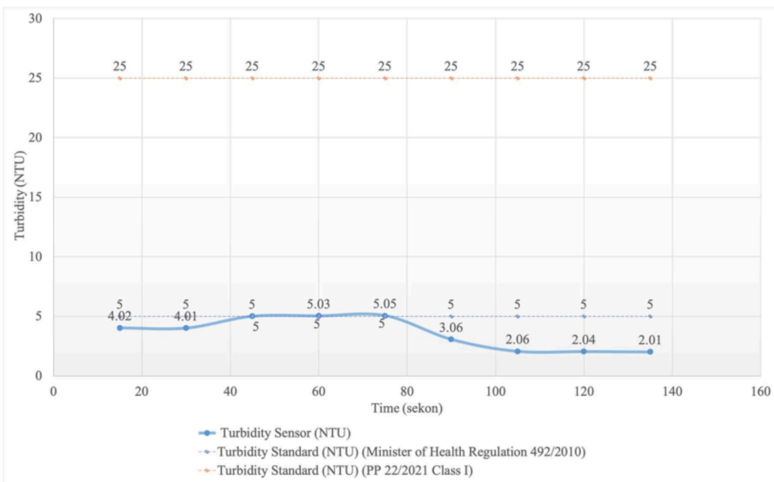

Figure 9. Comparison of turbidity sensor readings with regulatory standards over time

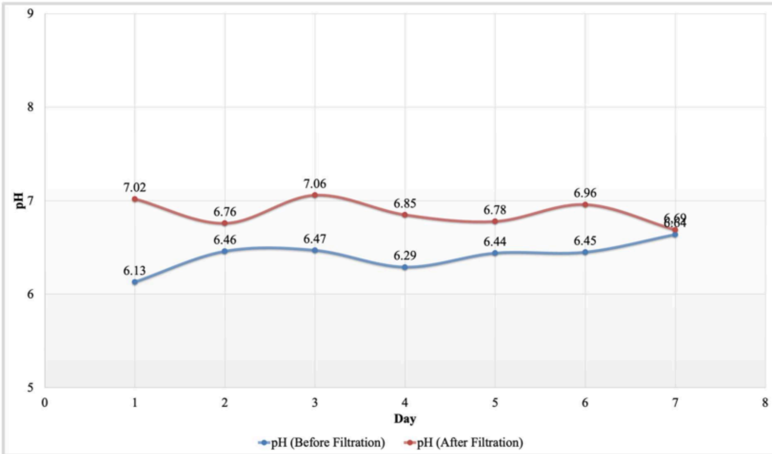

Figure 10. Comparison of water pH levels before and after filtration

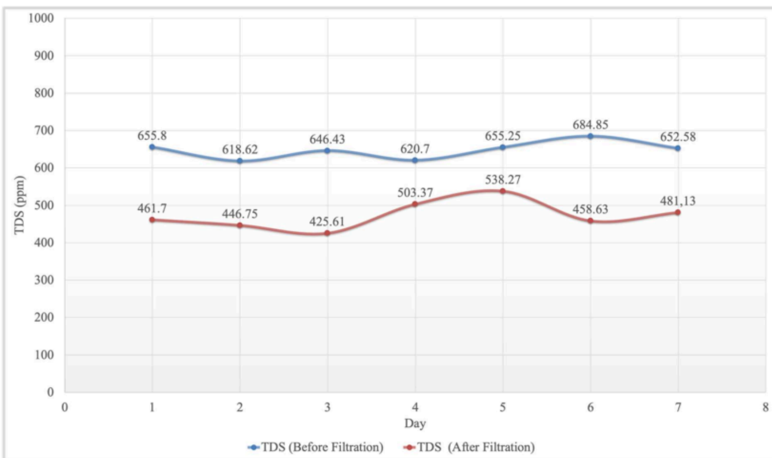

Figure 11. Comparison of total dissolved solids before and after filtration

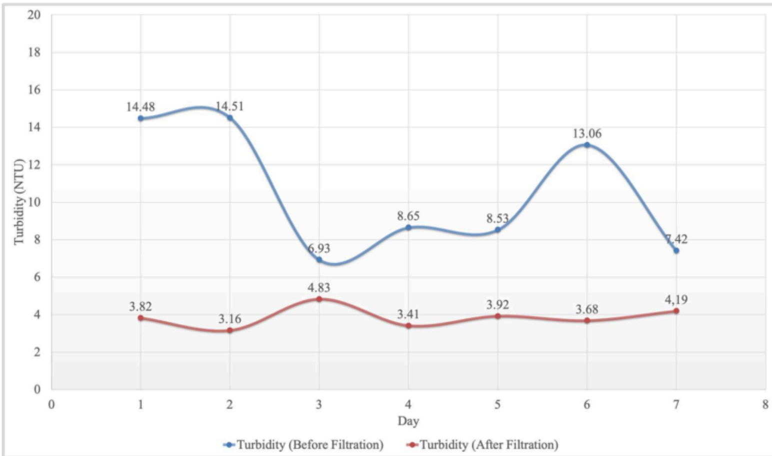

Figure 12. Comparison of water turbidity levels before and after filtration

CONCLUSIONS

This research successfully designed and developed an automatic filtration system and water quality monitoring system based on the Internet of Things (IoT) for use in fish farming systems. This system enables real-time monitoring and control of water quality through the integration of pH, turbidity, and TDS sensors, which are connected to actuators such as water pumps and solenoid valves. This actuator operates automatically when the water quality parameters exceed the safe limits. The test results show that this system is effective in improving water quality, as indicated by a 58.87% decrease in turbidity levels, an average decrease in TDS of 26.80%, and stability of pH values with an improvement of 7.3%. These values have complied with water quality standards based on Government Regulation No. 22 of 2021 as raw water, and in many cases also meet the Regulation of the Minister of Health No. 492 of 2010 for drinking water. The effectiveness of the sensors used is also relatively high, with the pH sensor showing an accuracy of 96.51%, the TDS sensor having an accuracy of 98.19%, and the turbidity sensor being able to record consistent results even though some of the values slightly exceed the limits of the Minister of Health Regulation, but still below the maximum limit of Government Regulation No. 22 of 2021. This demonstrates that the developed water quality monitoring system can provide accurate and reliable measurement results to support the automatic filtration process. This system has also proven to be more efficient than conventional methods, as it can reduce labor requirements, conserve water and energy usage, and provide early warning of significant changes in water quality. Support for data display via Android applications and LCD screens makes it easier for users to monitor. Overall, this system has great potential for implementation in the modern aquaculture industry, which prioritizes efficiency, sustainability, and environmental protection, aligning with the blue economy concept—a priority of the Indonesian government.

ACKNOWLEDGMENTS

The authors sincerely thank the Ministry of Marine Affairs and Fisheries and the Institute of Business and Technology Indonesia for their support during the research activity.

AUTHOR CONTRIBUTION

IGMND: Conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, and validation; IMAN: data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, visualization, writing – original draft, and writing – review and editing; AAGE: data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, and validation.

DECLARATION OF COMPETING INTEREST

The authors declare no competing interests.

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