Lontar Physics Today (e-ISSN: 2828-0970)
Vol. 5 No. 1 February 2026, p 115-133
Available online at http://journal3.upgris.ac.id/index.php/lpt/index
DOI: 10.26877/lpt.v5i1.352

Arduino-Based Automatic Water Salinity Control System Using a Gravity TDS Sensor

Widya Maharani Putri, Syahrir, Kholis Nurhanafi, Devina Rayzy Perwitasari Sutaji Putri, Ahmad Zarkasi, and Auliya Rahmatul Ummah*

Electronics and Instrumentation Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman, St. Barong Tongkok No. 04 Gunung Kelua, Samarinda, Indonesia

* Corresponding author(s), e-mail: auliya@fmipa.unmul.ac.id

Article Info:

Article History:
received: 20 January 2026
accepted: 17 February 2026
available online: 21 February 2026

Keyword:
Arduino, automatic control system, gravity TDS sensor, linear regression, water salinity

https://doi.org/10.26877/lpt.v5i1.352

Abstract:

Water salinity is one of the water quality parameters that plays an important role in maintaining aquatic environmental conditions. Instability in salinity levels can degrade water quality. Therefore, an automatic and continuous control system is required. This study aims to design and implement an Arduino-based automatic water salinity control system using a Gravity Total Dissolved Solid (TDS) sensor. The research methods include hardware and software design, sensor calibration, and system testing by comparing sensor measurements with reference values at several salinity variations expressed in ppm units. The preliminary data were analyzed using linear regression to determine the relationship between sensor reading and the reference values, as well as Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) to evaluate system accuracy. The test result show that the system was able to consistently track change in salinity, with stable readings at a 20% increase corresponding to 614.4 ppm and a 40% decrease corresponding to 296.0 ppm. These findings indicate that the Arduino-based automatic system combined with the Gravity TDS sensor has strong potential to be applied as an efficient solution for monitoring and controlling water salinity.

1. Introduction

Water quality is a significant factor that affects the stability of the aquatic environment and the success of various aquaculture activities. Water quality is determined by physical, chemical, and biological parameters, which must be maintained within acceptable quality thresholds (Chidinma, 2024; Yunarty et al., 2022). Physical parameters such as temperature, salinity, brightness, and water flow play an important role in maintaining the stability of the aquatic environment and supporting the growth and survival of aquatic organisms (Mustofa, 2020). Among these parameters, water salinity is one of the key parameters because it directly affects the condition of aquatic ecosystems, including freshwater, brackish water, and marine environments (Abd & Mohamed, 2023; Sharma & Bhatt, 2023).

Uncontrolled water salinity can cause changes in aquatic ecosystems and negatively impact aquatic organisms, including a decline in freshwater organisms that serve as natural food sources (Matysik et al., 2025). In aquaculture, it is essential to maintain water temperature and salinity within specific ranges to support organism growth. For example, Vannamei shrimp farming needs a temperature of 28-32°C and a salinity of 15-25 ppt (Toruan & Galina, 2023). In addition, the Total Dissolved Solids (TDS) parameter is used as an indicator of water quality, with TDS values below 500 mg/L, or equivalent to 0.5 ppt, considered safe according to WHO guidelines and national standards (Ikhwan et al., 2023).

Previous studies have developed various methods for measuring water salinity using different instruments. Navarrete used salinometers and refractometers to measure electrical conductivity and dissolved substance concentrations in water (Navarrete et al., 2024). Matsyik utilized the YSI ProDSS multiparameter instrument for soil and water salinity analysis (Matysik et al., 2025), while Gómez-Astorga used capacitance sensors to examine the relationship between electrical conductivity and salinity (Gómez-Astorga et al., 2024). The ARHEA modular system, developed by Purba, integrates several sensors to measure pH, turbidity, temperature, conductivity (or salinity), and dissolved oxygen in water (Purba et al., 2023).

Other studies have demonstrated the use of TDS and conductivity-based sensors for measuring water salinity. Parra integrated salinity sensors with Total Suspended Solids (TSS) measurements and reported good calibration results that were stable under temperature variations (Parra et al., 2023). Jáquez implemented a TDS sensor supported by the Gravity TDS library for integrations with a microcontroller-based system (Jáquez et al., 2023). In addition, Hakimi showed that TDS sensors, including the Gravity TDS sensor, can be used to measure salt concentrations and control water salinity using microcontrollers. (Hakimi et al., 2021).

However, most previous studies have focused primarily on salinity monitoring or measurement systems, without integrating automatic control mechanisms and providing quantitative evaluations of measurement accuracy. In many cases, system performance is only discussed qualitatively, making it difficult to objectively assess sensor reliability and control effectiveness. To address this gap, the novelty of this research lies in the development of an Arduino-based automatic water salinity control system that not only performs continuous salinity measurements using a Gravity TDS sensor but also integrates an automatic control mechanism and a quantitative system performance evaluation using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). This evaluation enables a more objective and measurable assessment of system accuracy compared to reference instruments.

Therefore, this study aims to design and implement an Arduino-based automatic water salinity control system using a Gravity TDS sensor, to evaluate system performance through salinity testing and sensor reading analysis, and to assess measurement accuracy by comparing sensor data with reference instruments based on RMSE and MAE parameters.

2. Theoretical Framework

2.1 Water Quality

Water quality is a critical factor that determines the stability of aquatic environments and the success of aquaculture activities. It refers to the physical, chemical, and biological conditions of water that influence its ability to support aquatic organisms. Poor water quality can lead to physiological stress, reduced growth rates, and increased mortality in cultured species (Ramadhan et al., 2020).

Water quality parameters for freshwater aquaculture activities are classified into three categories, namely physical parameters (temperature, salinity, brightness, and water flow), chemical parameters (oxygen content, alkalinity, pH, carbon dioxide, ammonia, nitrite, nitrate, and phosphate), and biological parameters (bacteria and plankton) (Mustofa, 2020). Maintaining these parameters within acceptable thresholds is essential, yet challenging, due to environmental fluctuations (Yunarty et al., 2022).

From a theoretical perspective, water quality parameters are interrelated rather than independent. Changes in one parameter may influence others and subsequently affect the overall stability of the aquatic environment. Therefore, water quality management requires not only monitoring but also control mechanisms that can respond to dynamic environmental changes.

2.2 Salinity

“Salinity” originates from the Latin word “salinus,” meaning “salt,” and is defined as the degree of saltiness or the amount of salt dissolved in water. The unit of salinity is expressed in g/kg, which is generally written as ‰ (parts per thousand). Salinity is one of the variables used to assess water quality in both groundwater and surface water. Therefore, salinity can also be defined as the concentration of dissolved salts in water (Bella et al., 2021).

In aquatic systems, salinity is a key chemical parameter because it directly affects osmotic pressure, ion regulation, and metabolic processes of aquatic organisms. Deviations from the optimal salinity range may cause physiological stress and reduce growth performance, particularly in aquaculture environments where organisms are highly sensitive to environmental changes. From a physical perspective, salinity is directly associated with the concentration of dissolved ions, such as sodium (Na^+) and chloride (Cl^-), which contribute to the conduction of electrical current in water. Accordingly, an increase in the concentration of dissolved ions enhances the electrical conductivity of water, which is quantitatively represented by electrical conductivity (EC). Consequently, variations in salinity directly influence EC values, allowing EC to be used as an indirect indicator of water salinity levels (Suminten et al., 2021). Relationship between salinity and electrical conductivity forms the basis for sensor-based salinity measurement methods. By measuring EC and converting it into related parameters such as Total Dissolved Solids (TDS), salinity can be estimated indirectly with sufficient accuracy for monitoring and control purposes (Haryono, 2021).

2.3 TDS Sensor Characteristics

To quantify the salinity levels discussed previously, a Total Dissolved Solids (TDS) sensor is employed. This sensor operates by measuring the solution’s electrical conductivity (EC) and converting it into a concentration value (mg/L or ppt) through a specific conversion factor. Since electrical conductivity is influenced by the concentration of dissolved ions, TDS values can be used as a quantitative indicator of salinity within certain concentration ranges. As a result, conductivity-based TDS sensors are frequently utilized in water quality monitoring and salinity estimation systems (Haryono, 2021).

One type of TDS sensor used in this study is the Gravity TDS sensor manufactured by DFRobot, as shown in Figure 1. The sensor operates with an input voltage of 3.3-5.5 V and provides an analog output voltage in the range from 0-2.3 V, with a current consumption of 3-6 mA. The measurement range is approximately 0-1000 mg/L, with an accuracy of ± 10% full scale at 25°C. The analog voltage output is read by the Arduino microcontroller through its analog-to-digital converter, enabling continuous salinity monitoring within the operating range required for the proposed control system (Jáquez et al., 2023).

The TDS sensor measures the electrical conductivity (EC) of water. Water conductivity is determined using an electrode sensor located on the TDS sensor probe. The primary measurement results displayed by a TDS sensor are typically expressed in ppt (parts per thousand) or mg/L. The TDS meter calculates the TDS value by multiplying the measured conductivity by a conversion factor, resulting in TDS values in ppt or mg/L. Both theoretically and empirically, there is a linear relationship between EC and TDS, which can be expressed in Equation 1,

$$TDS = kEC \tag{1}$$

where k denotes a conversion factor that depends on the characteristics of the dissolved ions in the water medium, for freshwater and brackish water, the value of k typically ranges from 0.55 to 0.8. EC denotes electrical conductivity, and TDS denotes the total concentration of dissolved substances in water. The obtained TDS value can subsequently be related to salinity, since salinity quantifies the concentration of dissolved salts in water. Consequently, variations in salinity lead to corresponding changes in EC, which are reflected in TDS values measured by the sensor (Handika & Irawan, 2024). The TDS Gravity sensor functions as a transducer that converts the physical property of electrical conductivity into an electrical signal, which can be processed digitally. Variations in salinity cause changes in EC, which are subsequently reflected in TDS values. Therefore, sensor accuracy depends on the stability of the EC-TDS relationship, electrode condition, and signal conversion process (Chuzaini & Dzulkiflih, 2022).

2.4 Microcontroller

The Arduino Uno functions as the primary control unit (brain) of the automation system, responsible for signal acquisition, data processing, and execution of control logic. In this system, the microcontroller performs two critical roles. First, it acts as a signal processor that converts the analog voltage signal from the TDS sensor (0-2.3V) into digital data using a 10-bit Analog-to-Digital converter (ADC). This process involves mapping the digital values (0-1023) to the corresponding salinity levels based on a pre-programmed calibration linear equation.

Second, the Arduino Uno implements a closed-loop control mechanism. It continuously compares the real-time salinity data with a predefined threshold (setpoint). When the salinity deviates from the optimal range, the microcontroller triggers a logic output to drive a relay modules, which in turn activates the actuators (pumps) to restore the salinity to the desired level. This automated response minimizes human error and ensures environmental stability, which is crucial for sensitive aquaculture species (Widharma & Wiranata, 2022).

2.5 Intergration of System Components and Theoretical Framework

Based on theoretical and empirical studies, water quality, salinity, TDS sensors, and the Arduino Uno constitute interrelated components in the development of automated salinity control systems. Water quality provides the conceptual context, salinity acts as the primary controlled variable, the TDS sensor functions as an indirect measurement instrument based on the principle of electrical conductivity (EC). In this configuration, the Arduino Uno serves as the central processing and control unit that bridges the gap between digital data and physical action.

Within this framework, sensor measurements are processed by the microcontroller and compared with predefined setpoints to generate control decisions. When a deviation occurs, the system triggers actuators to restore the salinity to its optimal range. The reliability of this integration is crucial, as the accuracy of the TDS sensor directly influences the precision of the control action. To ensure the system operates within scientific standards, the deviation between sensor-derived values and reference values is quantified using error metrics, specifically Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), which represent measurement consistency and average deviation, respectively.

Ultimately, this theoretical synergy ensures that the transition from environmental data to mechanical response is mathematically grounded and biologically relevant. By integrating physical principles with microcontroller-based logic, this framework provides a robust foundation for an automated system that mitigates salinity fluctuations, thereby enhancing the sustainability of aquaculture environments.

3. Method

3.1 System Design

This study employed an experimental method with a prototype design and testing approach for an automatic water salinity control system. The research was conducted using laboratory-scale water media representing various salinity conditions. The system was designed to continuously measure salinity using a Gravity Total Dissolved Solids (TDS) sensor and to automatically adjust salinity levels based on sensor readings processed by an Arduino microcontroller.

The control system operates after the monitoring data have been processed by Arduino. The measured salinity value is compared against the predefined upper and lower threshold limits. Based on this comparison, the Arduino controls the relay module, which functions as an electronic switch to activate or deactivate the water pump as an actuator.

The system control mechanism begins with system initialization, during which the Arduino performs the initial configuration of the TDS sensor, relay module, and two water pumps serving as actuators. Once the system is fully initialized, the TDS sensor performs an initial salinity measurement of the test medium. The measured salinity value is subsequently compared with the predefined upper and lower threshold limits, which are set at 500 ppm and 200 ppm, respectively. If the measured salinity exceeds the upper limit, the system classifies the water as excessively saline, and the Arduino activates the relay to switch on the freshwater pump in order to reduce salinity. Conversely, when the salinity value falls below the lower limit, the Arduino activates the saltwater pump, supplying a 0.9% NaCl solution, to increase salinity. Each pump operates for 30 seconds, then deactivates for 20 seconds to allow adequate mixing before the sensor acquires the next measurement. This sequence of measurement, comparison, and adjustment is continuously executed in a closed-loop manner until the salinity value returns to the desired range. Once stable salinity conditions are achieved, both pumps are deactivated, and the system reverts to automatic monitoring mode. Throughout the testing phase, sensor readings, pump activation duration, and salinity conditions are recorded and stored for subsequent system performance analysis.

A block diagram of the research system illustrating the workflow of the sensor, processing unit, and actuator is presented in Figure 1, which consists of seven main functional blocks. The power supply provides electrical energy to the Arduino Uno microcontroller, which serve as the central processing unit. The Gravity TDS sensor measures the electrical conductivity of the water test medium and transmits the corresponding analog signal to the Arduino Uno. Based on the processed salinity data, the Arduino generates control signals to the relay modules, which actuate the two water pumps responsible for freshwater and saltwater injection. The acclimation bucket functions as the reservoir for both freshwater and saltwater sources, while the laptop is used for monitoring and data acquisition during system testing.

The hardware implementation of the system is illustrated in Figure 2, which presents the prototype circuit design based on the Arduino Uno platform. In this figure, TDSM1 represents the Gravity TDS sensor module used to measure salinity in the water medium. LCD1 denotes the liquid crystal display, which displays real-time information, including the measured salinity (in ppm) and system status. The LCD resolution allows numerical salinity values to be displayed clearly within the operating measurement range of the sensor.

The relay modules are labelled RL1 and RL2, corresponding to the freshwater pump and saltwater pump control channels, respectively. In the prototype schematic, the pumps are represented by electrical load symbols (VIN and lamp symbols), indicating their function as actuated devices. The Arduino Uno continuously processes sensor data, updates the LCD display, and performs automatic salinity adjustment within a single closed-loop control system.

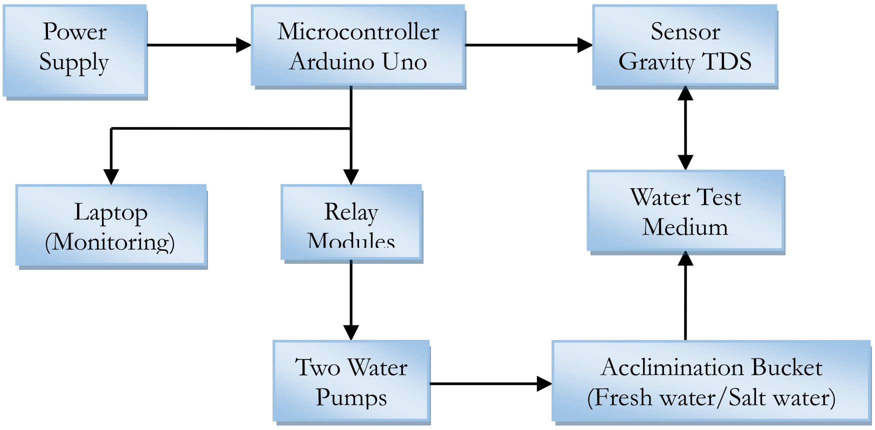

Figure 1. *System Block Diagram*

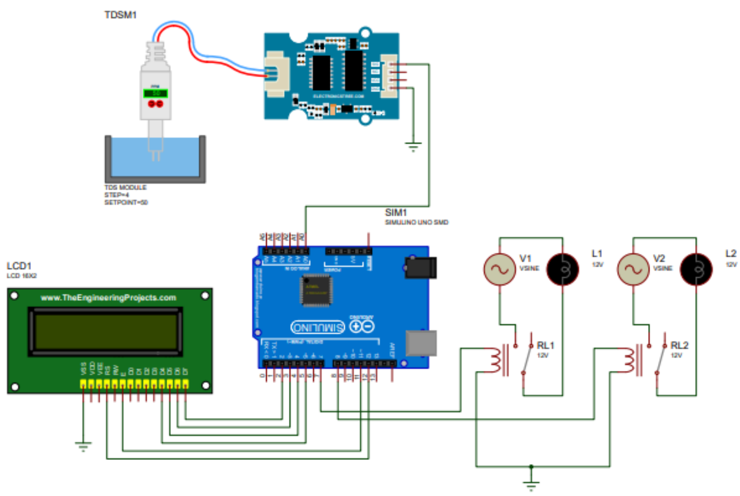

Figure 2. *Prototype Design*

3.2 Testing and Data Collection Procedures

The main components used in this study included an Arduino microcontroller as the central processing unit, a Gravity TDS sensor for measuring water salinity, and two water pumps serving as actuators for the salinity adjustment mechanism. The test medium was prepared with water containing varying concentrations of dissolved salts to represent different salinity conditions encountered during system evaluation. All experiments were conducted under controlled environmental conditions in the Electronics and Instrumentation Laboratory to minimize the influence of external disturbances on the measurement results.

System testing was performed by applying several salinity variations to the test water medium within a defined experimental duration, with sensor data recorded at regular sampling intervals. The measured data were used to evaluate the sensor's accuracy by comparing its readings with those from a reference measurement instrument, and to assess the overall performance of the automatic salinity control system in maintaining salinity within the desired setpoint range. To ensure the system's stability, repeatability, and reliability, each testing scenario was repeated over a defined experimental duration.

During testing and data collection, the TDS sensor was continuously immersed in the test medium to enable real-time salinity monitoring and closed-loop control. Continuous immersion enabled the system to promptly detect salinity deviations and activate the appropriate pump to restore salinity levels. However, prolonged immersion of the sensor probe may lead to salt accumulation on the electrodes, potentially affecting measurement accuracy over time. To mitigate this effect, the sensor probe was periodically removed and cleaned at predetermined intervals throughout the experiment. This procedure ensured that the sensor maintained stable performance and that the collected data accurately represented the actual salinity conditions of the test medium.

3.3 Data Analysis Methods

This section describes the data analysis procedures used to evaluate the performance of the proposed automatic water salinity control system. The analysis was conducted in two stages, namely preliminary sensor validation and system performance evaluation, to ensure measurement reliability and control effectiveness.

Sodium chloride (NaCl) was used as the salinity source in this study because it provides a stable and well-defined iconic composition that directly influences electrical conductivity, which forms the basis of EC-TDS-based salinity measurement. The use of NaCl allows controlled adjustment of dissolved ion concentration and is commonly applied as a reference solution in salinity and conductivity-based sensor evaluation. The salinity test range of 100-600 ppm was selected to ensure compatibility with the effective working range of the Gravity TDS sensor and to represent water conditions from freshwater to low-brackish encironments. This range enables evaluation of sensor response and control system performance under salintiy levels relevant to aquaculture applications while maintaining measurement reliability.

3.3.1. Preliminary Sensor Validation

In the preliminary testing stage, the Gravity TDS sensor was evaluated under controlled laboratory conditions to examine the relationship between sensor readings and theoretical salinity values. Reference salinity values were calculated theoretically using the dilution equation, according to

$$C_1V_1 = C_2V_2 \tag{2}$$

where C_1 denotes the initial solution concentration (ppm), V_1 denotes the initial solution volume (mL), C_2 is the solution concentration after dilution (ppm), and V_2 denotes to the solution volume after dilution (mL).

In the linear regression analysis, the relationship between sensor measurements and reference values is expressed as Equation 3, where a represents the sensor sensitivity (gain) relative to the reference measurement, and b represents the offset associated with systematic measurement bias. The deviation from ideal behavior is evaluated by examining the proximity of a to unity and the magnitude of b relative to the measurement range.

$$y = ax + b \tag{3}$$

This theoretical approach was used to generate reference salinity values during the preliminary stage, allowing controlled adjustment of salinity levels through known dilution ratios. Linear regression analysis was then applied to evaluate the linear relationship between Gravity TDS sensor readings and the theoretically calculated sainity values. This stage aimed to verify sensor linearity and suitability for further integration into the automatic control system.

3.3.2. *Definition Of Variables*

To ensure consistency between the data analysis methods and the experimental result, the variables used in this study are defined in Table 1.

Table 1. *Experimental variables*

Variable	Description	Unit
S_i	Salinity value measured by the Gravity TDS sensor at sample i	ppm
R_i	Reference salinity value at sample i, obtained from a calibrated reference measuring instrument	ppm
V_{NaCl}	Volume of 0.9% NaCl solution injected by the saltwater pump	mL
V_{fw}	Volume of freshwater injected by the freshwater pump	mL
V_{tot}	Total volume of the mixed solution resulting from the combination of V_{fw} and V_{NaCl}, maintained at 200 mL for all experimental	mL
S_{sp}	Setpoint salinity value defined as a single target salinity value set at 500 ppm, which serves as the reference operating point for the control system	ppm
S_{upper}	Upper salinity threshold value defined for each experimental scenario, used to trigger freshwater injection when the measured salinity exceeds the specified limit	ppm
S_{lower}	Lower salinity threshold value defined for each experimental scenario, used to trigger saltwater injection when the measured salinity exceeds the specified limit	ppm
S_{on}	Salinity value measured at the moment when the pump is activated, indicating the salinity that triggers the control action	ppm
S_{final}	Salinity value measured after the control process is completed and the system reaches a stable condition	ppm
t_{pump}	Total duration during which the pump is activated in a given test condition	s
t_{sys}	Total time required the system to complete the salinity adjustment process and reach a stable condition	s
n	Total number of data points used in the analysis	-

3.3.3. *Control System Data Analysis*

During system operation, salinity values measured by the Gravity TDS sensor are continuously monitored and compared with predefined upper and lower threshold limits. If the measured salinity exceeds the upper limit (S_{upper}), the freshwater pump is activated to reduce salinity by injecting freshwater with volume V_{fw}. Conversely, if the measured salinity falls below the lower limit (S_{lower}), the salitwater pump injects a 0.9% NaCl solution with volume V_{NaCl} to increase salinity.

The system aims to regulate salinity toward the setpoint value of 500 ppm while maintaining stability within the defined threshold limits. Pump activation duration, injected solution volumes, and resulting salinity values are recorded for each control cycle. This analysis enables evaluation of the system's responsiveness, stability, and ability to maintain salinity within the desired operational range.

3.3.4. *Sensor Accuracy And Error Analysis*

Salinity values were derived from TDS sensor readings, which measure the concentration of dissolved substances in water expressed in parts per million (ppm). The obtained TDS data were subsequently converted into salinity values using an empirical relationship between TDS and salinity, in which salinity is defined as a function of dissolved substance concentration. The converted salinity values were then used as the system measurement values (S_i) in the calculation of performance evaluation. To assess measurement accuracy, the sensor-derived salinity values (S_i) were compared with reference salinity values (R_i) obtained from a calibrated reference measuring instrument. The deviation between S_i and R_i was quantified using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE).

The system accuracy was evaluated using the Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) parameters, which were calculated using Equations 4 and 5, respectively. The RMSE value denotes the magnitude of the mean squared error, while MAE denotes the mean absolute error between the sensor measurements and reference values. The lower RMSE and MAE values indicate better performance of the developed water salinity measurement and control system.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - R_i)^2} \quad (4)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|S_i - R_i| \quad (5)$$

Where S_i denotes the salinity value obtained from the TDS sensor reading, while R_i denotes the corresponding reference salinity value. The variable n refers to the total number of test data points used in the analysis. RMSE reflects the magnitude of overall measurement deviation by emphasizing larger errors, while MAE represents the average absolute deviation between sensor measurements and reference values. Lower RMSE and MAE values indicate higher measurement accuracy and better system performance.

In addition to RMSE and MAE, the absolute deviation between sensor measurements and reference values was also examined. The absolute deviation is defined as the absolute difference between the sensor-derived salinity value and the corresponding reference value, expressed as $|S_i - R_i|$. The smallest deviation refers to the minimum value $|S_i - R_i|$ observed among all test samples and is used as an additional indicator to evaluate the closeness of the sensor measurement to the reference value under specific test conditions.

3.3.5. Data Interpretation

All measured and calculated data, including salinity values, injected solution volumes, and error metrics, are presented in tabular and graphical form in the results section. The analysis focuses on identifying trends in sensor accuracy, system response behavior, and control effectiveness relative to the predefined salinity thresholds. This structured data analysis ensures consistency between the theoretical framework, data analysis methods, and experimental results

4. Result

4.1 Water Salinity Measurement Results

Preliminary testing was conducted to evaluate the accuracy of the TDS sensor in measuring the salinity of NaCl solutions within the range of 0-600 ppm using six different concentration levels. Each sample was measured five times, and the average value was calculated to obtain more representative data, as presented in Table 2.

Table 2 shows the system response under different salinity conditions, including pump activation behavior and the resulting salinity changes relative to the defined setpoint. Based on the preliminary test result presented in Table 2, the comparison between reference values and sensor readings showed that all average salinity values were very close to the corresponding reference values. The relatively small differences in readings indicate that the sensor operates consistently across a range of solution concentrations. The best measurement performance was obtained from samples with a reference value of 100 ppm, where the average sensor reading was 100.60 ppm, showing the smallest deviation from the reference value. Meanwhile, the largest deviation occurred in samples with a reference value of 400 ppm, with an average reading of 402.40 ppm, which showed the greatest difference compared to other samples, although this value remained within the acceptable measurement tolerance.

Table 2. *Preliminary Test Result*

Test No.	R_i	V_{NaCl}	V_{fw}	V_{tot}	S_i
1	100	2	198	200	100.6
2	200	4	196	200	201.4
3	300	6	194	200	301.6
4	400	8	192	200	402.4
5	500	12	188	200	501.8
6	600	14	186	200	602.8

Further sample variation testing was conducted to evaluate the system's ability to automatically adjust water salinity to a target value of 500 ppm. Testing was performed under two conditions, which are increasing and decreasing salinity, with each condition experiencing a change in levels of 10%, 30%, and 50%, as shown in Table 3.

Table 3. *Sample Variation Measurement Result*

Test Condition	S_{sp}	S_{upper}	S_{lower}	S_{on}	S_{final}	t_{pump}	t_{sys}
Increase 10%	500	550	500	557.0	501.2	60	100
Increase 30%	500	650	500	665.0	503.4	120	200
Increase 50%	500	750	500	765.8	501.0	150	250
Decrease 10%	500	500	450	443.0	500.4	30	50
Decrease 30%	500	500	350	306.2	506.3	90	150
Decrease 50%	500	500	250	246.8	501.0	150	250

Table 3 presents the system response under different salinity variation conditions and forms the basis for performance evaluation. In both salinity increase and decrease scenarios, the control system is activated when the measured salinity exceeds the upper limit or falls below the lower limit. The salinity value at system activation (ON state) reflects the system's responsiveness to salinity changes.

Under salinity increase conditions, the fastest system response was observed in the 10% test condition, where pump activation occurred at a salinity of 557.0 ppm, which was only 7 ppm above the upper limit of 550 ppm. Under this condition, the system required the shortest total response time of 100 seconds to reduce salinity to a value to the target of 500 ppm. In contrast, higher variation levels resulted in longer response times due to larger deviations from the target salinity.

For salinity reduction scenarios, system activation was influenced by the proximity of the initial salinity value to the lower threshold. The system exhibited the fastest activation in the 50% reduction condition, with a salinity of 246.8 ppm, only 3.2 ppm below the lower limit of 250 ppm. However, this condition required a total system response time of 250 seconds to increase salinity to a value close to the target of 500 ppm, indicating that the magnitude of the initial deviation from the target value continues to influence the system's adjustment time.

In addition to response time and activation behavior, differences in final salinity values were observed in the test conditions. As shown in Table 3, the 30% test condition, for both salinity increase and decrease scenarios, yielded higher initial salinity values than the 10% and 50% conditions. This behavior is associated with the control system's dynamic response during the salinity adjustment process. At the 30% condition, the balance between the injected NaCl solution and the freshwater volume produces a moderate rate of salinity change, which may lead to a transient overshoot before the system reaches a stable state. In contrast, the 10% condition induces smaller salinity changes that are more rapidly damped, while the 50% condition triggers stronger corrective action due to larger salinity variations.

This behavior represents a transitional regime in which system response dynamics are more pronounced and is considered a normal characteristic of threshold-based control systems operating with fixed actuation durations. The observed phenomenon does not indicate sensor malfunction or abnormal measurement deviation, but rather highlights the influence of mixing dynamics and control response characteristics on the final salinity values.

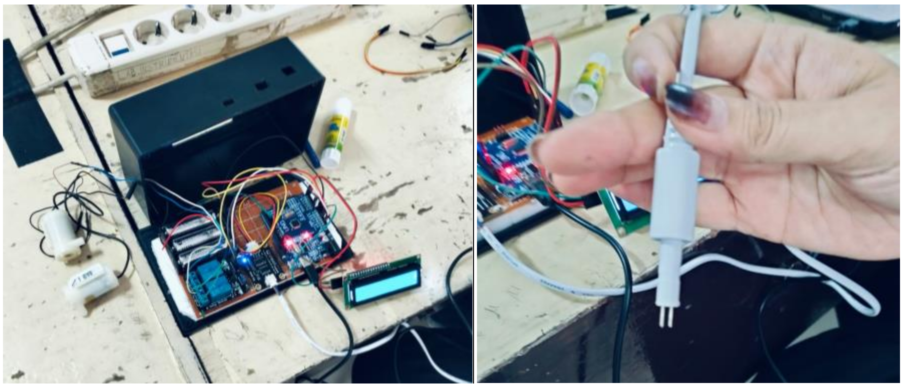

Figure 3. *Prototype of water salinity measurement*

4.2 Analysis Of Gravity TDS Sensor Readings

Based on the result presented in the previous section, the graphical representation of the collected data illustrates the relationship between the sensor readings and the corresponding measurement conditions. The graph shows a consistent trend between the measured TDS values and the corresponding reference data, indicating that the sensor captures TDS variations accurately. Minor fluctuations observed at several data points indicate measurement deviations, a common phenomenon in sensor-based systems. Overall, these graphical results provide an initial assessment of sensor performance and serve as the basis for further analysis of the Gravity TDS sensor readings in the subsequent section.

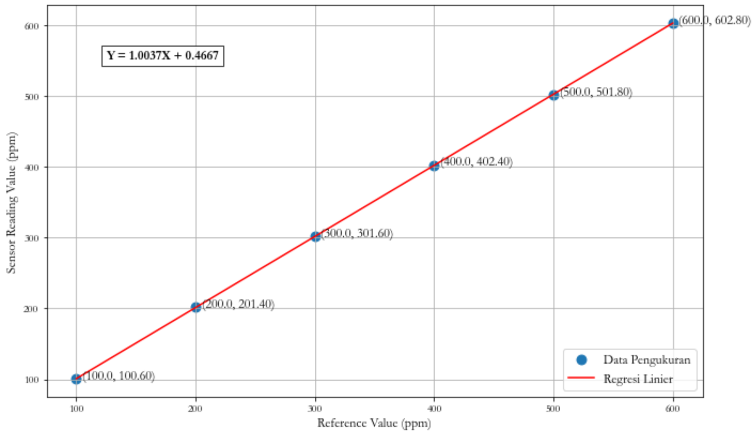

Figure 4. *Correlation Between Reference and Reading Value*

The graph in Figure 4 illustrates the relationship between reference salinity values and TDS sensor readings within the range of 100-600 ppm. All measurement data points lie close to the linear regression line, indicating a strong linear relationship between the reference values and sensor readings. This demonstrates that the TDS sensor can consistently track salinity changes across different solution concentrations. The linear regression equation is expressed as $y = 1.0037x + 0.4667$ where y

represents the sensor-derived salinity value and x represents the reference salinity value obtained from the calibrated measured instrument. In this equation, the regression coefficient (1.0037) represents the sensitivity or gain of the sensor relative to the reference measurement. A regression value close to unity indicates that the sensor response is nearly proportional to the reference salinity across the tested range, reflecting high linearity and consistent measurement behavior. The intercept value (0.4667 ppm) represents a small systematic offset, which corresponds to a minor measurement bias when extrapolated toward zero salinity.

Considering the measurement range of 100-600 ppm, the intercept magnitude is negligible relative to the full-scale range, indicating minimal systematic error. In this analysis, minimal error is reflected by the combination of a slope close to one and a small intercept value, rather than by a predefined numerical error threshold. The regression result, therefore, confirms that the Gravity TDS sensor demonstrates reliable proportional behavior within the tested salinity range.

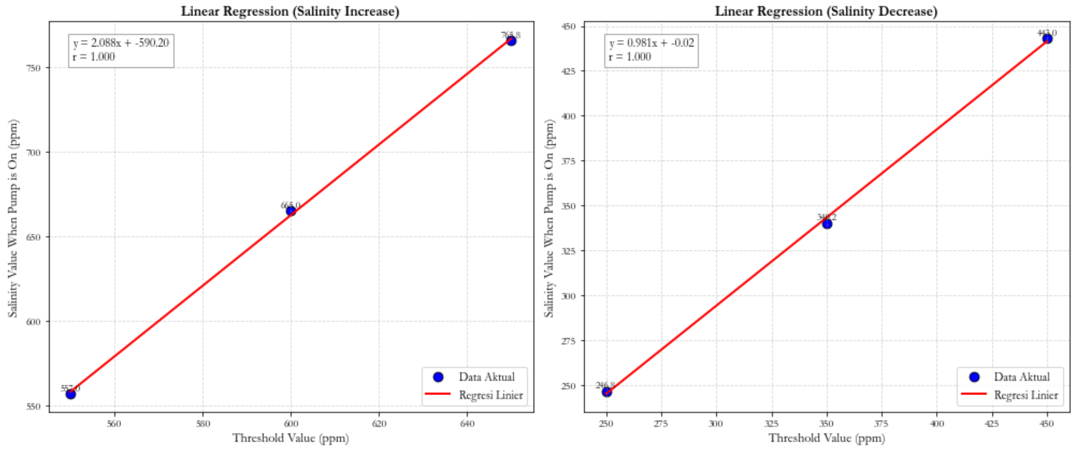

Figure 5. Linear Regression Of Salinity Sample Variation

Figure 5 presents the regression analysis of system response characteristics under salinity increase and salinity decrease conditions. The relationship is modelled using the linear equation $y = 2.088x - 590.20$ where y represents the system response parameter (e.g., response time or salinity adjustment behavior), x represents the salinity variation level, a denotes the response coefficient (system gain), and b represents the response offset. For the salinity increase condition, the regression coefficient $a = 2.088$ indicates a stronger response rate, reflecting the more pronounced effect of NaCl injection on increasing ion concentration and electrical conductivity in the solution. In contrast, the decrease condition yields a coefficient $a = 0.981$, indicating a comparatively lower response rate associated with freshwater dilution.

These coefficients are not expected to be identical because the physical processes governing salinity increase and decrease differ in terms of mixing dynamics, ion concentration gradients, and dilution mechanisms. The larger coefficient in the increase condition suggests that the salinity rise per unit variation is more pronounced than the salinity reduction under similar proportional conditions. This asymmetry reflects the inherent system dynamics rather than measurement inconsistency. No explicit threshold value is imposed in the regression analysis of Figure 5. The coefficients are derived empirically from experimental data and represent the observed system behavior under defined testing conditions.

4.3 *Error Analysis Using RMSE And MAE*

The performance of the proposed system was evaluated using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) based on six experimental data points. The calculated RMSE value was 1.902 ppm, while the MAE value was 1.76 ppm, indicating that the deviation between sensor-derived salinity values and reference measurements remains relatively small within the tested range.

The relatively low RMSE value suggests that large deviations are limited and that the overall prediction error magnitude is small across all experimental conditions. Since RMSE penalizes larger errors due to the squared term, it is more sensitive to outliers compared to MAE and therefore reflects the presence of extreme deviations more strongly (Hodson, 2022). The MAE value, being slightly lower than the RMSE, indicates that the average absolute deviation between measured and reference values is consistently small and that error dispersion remains uniform across the dataset.

The close proximity between RMSE and MAE values further suggests that extreme measurement errors are minimal and that no dominant outlier significantly influences the error distribution. As reported in recent studies, when RMSE and Mae exhibit similar magnitudes, the error distribution can be considered relatively stable and free from severe fluctuation (Hodson, 2022; Misiurek et al., 2025).

Considering the operational salinity range of 100-600 ppm, the obtained error values are less than 0.5% of the full-scale measurement range, indicating a high level of measurement reliability. These results confirm that the developed automatic salinity control system demonstrates satisfactory measurement accuracy and consistent predictive behavior within the operational range.

5. Discussion

5.1 *Interpretation of The Findings*

This study was compared with several previously published works that employed microcontroller-based systems for water quality monitoring, including studies by Irawan, Saraswati, Burhanudin, and Chuzaini. In general, these studies demonstrated that integrating rArduino- of ESP32-based sensors, such as TDS, pH, and turbidity sensors, enables real-time monitoring of water quality parameters. However, most of these systems were primarily designed for passive monitoring and lacked automatic control mechanisms capable of actively responding to changes in water quality (Burhanudin et al., 2024; Chuzaini & Dzulkiflih, 2022; Irawan et al., 2021; Saraswati et al., 2025).

Irawan developed an Arduino-based water quality monitoring system that uses TDS and pH sensors, with an automatic filtration mechanism activated when sensor readings exceed predefined thresholds. Although the system demonstrated the ability to improve water quality through filtration, the applied control strategy remained passive and did not support continuous or dynamic adjustment of water parameters. The system was primarily intended for household borehole water applications, which differ substantially from hatchery environments that require active and precise salinity regulation (Irawan et al., 2021). Similarly, Saraswati proposed an Arduino-based prototype for monitoring TDS and turbidity in refillable drinking water systems. Their results showed good sensor accuracy under static testing conditions, but the system was limited to tracking functions and designed for environments with relatively stable water characteristics (Saraswati et al., 2025). Burhanudin also developed an IoT-based monitoring system for fish ponds using Gravity TDS sensors and GSM communication, reporting relatively small TDS fluctuations (300–304 ppm and 442–446 ppm), which indicate stable sensor performance under constant environmental conditions. However, no automatic intervention mechanism was implemented to correct deviations in water quality parameters (Burhanudin et al., 2024).

Saraswati and Chuzaini reported more detailed quantitative evaluations of TDS sensor accuracy under static conditions. Saraswati reported measurement errors ranging from 0.32% to 4.02% relative to standard TDS meters, based on repeated measurements of five water samples (Saraswati et al., 2025). Chuzaini reported even higher accuracy for Gravity TDS sensors, with errors ranging from 0.109% to 0.189% and accuracy exceeding 99.8% in comparisons with SNI-certified TDS meters across multiple sampling locations, with TDS values ranging from 318 to 551 ppm (Chuzaini & Dzulkiflih, 2022). These results confirm that TDS sensors can achieve excellent accuracy when used in monitoring systems operating under relatively static, controlled conditions.

In contrast to these previous studies, the present research integrates the TDS sensor into a closed-loop salinity control system that includes pump actuators, resulting in a more dynamic operating environment dbyriven to active mixing and regulation. Under such conditions, measurement variability is influenced not only by intrinsic sensor characteristics but also by system response time, actuator operation, and fluid mixing dynamics. The regression analysis demonstrates substantial proportionality between sensor-derived and reference values, with a slope close to unity and a small intercept, indicating stable linear behavior and minimal systematic bias within the tested salinity range.

The obtained RMSE and MAE values further confirm that overall deviations remain relatively small compared to the operational range of 100-600 ppm. The close magnitude between these two metrics suggests a stable error distribution with no dominant outliers. In dynamic control systems, such numerical evaluation is essential because measurement performance reflects not only sensor precision but also the combined effects of control logic and environmental mixing.

Furthermore, Gómez-Astorga demonstrated that variations in salinity can cause output deviations of up to 30% in low-cost soil sensors, highlighting their sensitivity to environmental conditions when compensation mechanisms are not applied (Gómez-Astorga et al., 2024). This behavior reflects system dynamics during mixing and regulation, highlighting the complexity inherent in automated salinity control compared to passive monitoring systems. Although the context differs from that of water-based TDS measurement, these findings support the view that sensor performance in dynamic environments must be evaluated using robust numerical metrics. Therefore, the use of RMSE and MAE in this study is appropriate for capturing the combined effect of sensor behavior and control system dynamics.

Overall, this comparison demonstrates that while previous studies achieved high accuracy under static monitoring conditions, the present study advances existing work by enabling automatic salinity regulation through a closed-loop control strategy and by quantitatively evaluating system performance under dynamic conditions. This transition from passive monitoring to active regulation represents a significant methodological contribution toward practical hatchery-scale salinity management, despite the increased system complexity introduced by dynamic control conditions.

5.2 Limitation

The salinity measurement is derived from a TDS sensor, which provides an indirect estimation of salinity and may be affected by the type of dissolved substances present in the water. The control strategy implemented in this system employs a threshold-based ON-OFF algorithm, which may induce fluctuations around the setpoint and does not offer fine-grained control compared with more advanced control approaches. In addition, the overall system performance is influenced by the response time and flow rate of the water pumps, which can introduce delays in salinity adjustment.

The water pumps and relay modules used in this prototype are designed for small-scale operation, limiting the system's applicability to laboratory or hatchery-scale environments. Scaling the system for larger aquaculture facilities would require higher-capacity actuators and more robust power management. Furthermore, the TDS probe used in this study has relatively small physical dimensions, which may limit its representativeness in larger or more turbulent water bodies.

Environmental factors, such as temperature variations and sensor calibration conditions, were not extensively evaluated in this study. Although the current prototype is enclosed in a protective housing and provides clear real-time salinity readings through an LCD interface, further development is required to enhance long-term durability, industrial-grade packaging, and system scalability. Therefore, additional improvements are necessary to strengthen measurement accuracy, control stability, and overall system robustness.

5.3 Impact

This research developed an integrated system that combines real-time salinity monitoring with automatic control based on sensor feedback. The relay-or-pump-based control mechanism enables the system to respond directly and promptly to changes in TDS levels, in accordance with the operational requirements of the hatchery environment. In practical terms, this system has the potential to enhance water quality stability and reduce reliance on manual operator intervention. From a broader applied-physics perspective, this research demonstrates how fundamental principles such as electrical conductivity, signal conversion, and feedback control can be translated into an operational embedded system for environmental regulation. The developed approach may also be extended to water quality assessment in coastal or rural regions, where monitoring dissolved solids is essential for evaluating drinking water suitability. Since conductivity-based sensing reflects ionic concentration, the same framework may be adapted for estimating other dissolved ionic species through appropriate calibration models.

Beyond its application in aquaculture, this research also has broader implications for physics instrumentation and applied physics education. The proposed system employs low-cost sensors, microcontrollers, and fundamental physics principles, including electrical conductivity, signal processing, and feedback control, making it suitable as an experimental learning platform in physics education. Through this system, students can explore the integration of sensing, data acquisition, and control within a single experimental framework. Furthermore, the platform may be expanded to measure additional physical quantities, such as temperature, pressure, turbidity, or flow rate. Thereby illustrating the versatility of microcontroller-based instrumentation in experimental physics. Due to its simplicity, affordability, and ease of replication, the system is relevant for use in educational institutions with limited laboratory resources, thereby contributing to the global development of experiment-based physics education.

6. Conclusion

This study demonstrates that an Arduino-based automatic control system integrated with a Gravity Total Dissolved Solids (TDS) sensor can achieve the research objectives of automatically measuring and regulating water salinity at the laboratory scale. The experimental results confirm that the Gravity TDS sensor exhibits a linear and proportional response to changes in dissolved substance concentration, as indicated by a regression slope close to unity and a minimal intercept. This finding confirms its suitability as the primary component in a water salinity monitoring system within the tested operational range of 100-600 ppm.

In addition, implementing a closed-loop control system enables continuous detection and correction of salinity deviations toward a predefined setpoint. The system successfully regulated salinity under dynamic mixing conditions, and observed transient variations were identified as normal threshold-based control responses rather than sensor instability. One of the main strengths of the proposed system lies in its ability to actively regulate salinity through a closed-loop control strategy rather than relying solely on passive monitoring.

Furthermore, the relatively low error values from RMSE and MAE evaluations indicate that the integration of the sensor, microcontroller, and actuators operates stably and reliably, even under dynamic conditions arising from water-mixing processes. The calculated RMSE (1.902 ppm) and MAE (1.76 ppm) values demonstrate that overall measurement deviations remain small relative to the operational salinity range, indicating stable error distribution and satisfactory system accuracy. This demonstrates that the integration of sensors, microcontrollers, and actuators operates synchronously to maintain water salinity stability without manual intervention. Therefore, the research objective of developing and quantitatively validating an automatic salinity control system has been achieved.

As a direction for future work, this research may be extended to include large-scale system testing and the integration of temperature-compensation mechanisms and reference measurement instruments to enhance the system's accuracy and reliability under more dynamic environmental conditions. Further improvements may also include implementing advanced control algorithms and optimizing scalability for broader aquaculture applications.

Author's Contribution

Widya Maharani Putri: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Syahrir:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision. **Kholis Nurhanafi:** Conceptualization, Methodology, Writing – review & editing. **Devina Rayzy Perwitasari Sutaji Putri:** Conceptualization, Methodology, Writing – review & editing. **Ahmad Zarkasi:** Conceptualization, Methodology, Writing – review & editing. **Auliya Rahmatul Ummah:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision

Ethical Statement

This research was conducted through system development and experimental testing involving water quality sensors. The study did not involve human participants, animal subjects, or sensitive personal data. All procedures were performed in accordance with applicable institutional research guidelines. Because no human or animal subjects were involved, ethical approval and informed consent were not required.

Declaration of AI Use

Artificial intelligence-based tools were used solely to support the manuscript preparation process. ChatGPT was used to improve sentence clarity, coherence, and readability of the Indonesian draft. DeepL was used to translate the initial draft from Indonesian into English. Grammarly was subsequently employed to refine the English language, including grammar, spelling, punctuation, and writing style. The use of their tools was strictly limited to linguistic assistance and did not involve data analysis, interpretation of results, or generation of scientific content. All AI-assisted outputs were carefully reviewed and revised by the authors, who remain fully responsible for the accuracy, originality, and integrity of the final manuscript.

Conflict of Interest

The authors declare that there are no financial, professional, or personal interests that could have influenced the conduct of the research or the preparation of this manuscript.

Supplementary Materials And Data Availability

There is currently no publicly available repository for the data generated in this study. However, selected datasets and supporting materials relevant to the finding are available from the corresponding author upon reasonable request, subject to institutional policies.

References

Abd, A. El, & Mohamed, G. A. (2023). A neutron Scattering Method for Monitoring Water Salinity during Desalination Processes. *Journal of Radiation and Nuclear Applications*, *8*(2), 145–150. https://doi.org/10.18576/jrna/080207

Bella, A., Putri, D. R. P. ., & Mandang, I. (2021). Rancang Bangun Sistem Monitoring Suhu dan Salinias pada Air Laut. *Progressive Physics Journal*, *2*(1), 37–48. https://doi.org/10.30872/ppj.v2i1.767

Burhanudin, M. D., Widayaka, P. D., & Tjahyaningtijas, R. R. H. P. A. (2024). Design And Development of a Pond Water Quality Monitoring Device Using the GSM SIM-800L Module. *Indonesian Journal of Electrical and Electronics Engineering (INAJEEE)*, *7*(2), 44–49. https://doi.org/https://doi.org/10.26740/inajeee.v7n2

Chidinma, M. M. (2024). Bacteriological evaluation of fish pond waste water from different fish ponds in Owerri Imo State , Nigeria. *World News of Natural Sciences*, *53*, 223–230. https://psjd.icm.edu.pl/psjd/element/bwmeta1.element.psjd-533429ac-ed7f-42eb-ba45-5b10665d91b2

Chuzaini, F., & Dzulkiflih. (2022). IoT Monitoring Kualitas Air dengan Menggunakan Sensor Suhu , pH , dan Total Dissolved Solids (TDS). *Jurnal Inovasi Fisika Indonesia (IFI)*, *11*(3), 46–56. https://ejournal.unesa.ac.id/index.php/inovasi-fisika-indonesia/article/view/48240

Gómez-Astorga, M. J., Villagra-Mendoza, K., Masís-Meléndez, F., Ruíz-Barquero, A., & Rimolo-Donadio, R. (2024). Calibration of Low-Cost Moisture Sensors in a Biochar-Amended Sandy Loam Soil with Different Salinity Levels. *Sensors*, *24*(18), 1–18. https://doi.org/10.3390/s24185958

Hakimi, A. R., Rivai, M., & Pirngadi, H. (2021). Sistem Kontrol dan Monitor Kadar Salinitas Air Tambak Berbasis IoT LoRa. *Jurnal Teknik ITS*, *10*(1), A9–A14. https://doi.org/10.12962/j23373539.v10i1.59612

Handika, M. F., & Irawan, D. (2024). Rancang Bangun Alat Pengujian Air Pada Damiu Berbasis Iot Menggunakan Metode SAW. *Jurnal Teknika*, *18*(2), 661–671. https://doi.org/10.5281/zenodo.13159003

Haryono. (2021). *Pengaruh Penambahan Resin Saset Dalam Perebusan Air Sadah Terhadap TDS* (1st ed.). Poltekkes Jogja Press. https://eprints.poltekkesjogja.ac.id/8165/

Hodson, T. O. (2022). Root-mean-square error (RMSE) or mean absolute error (MAE): when to use them or not. *Geoscientific Model Development*, *15*(14), 5481–5487. https://doi.org/10.5194/gmd-15-5481-2022

Ikhwan, S., Marindani, E. D., & Jati, D. R. (2023). Design and Bevelopment of River Water Quality Monitoring and Salinity Development Properly Realtime Based IoT. *Telecommunications, Computers, and Electricals Engineering Journal (TELECTRICAL)*, *1*(2), 136–149. https://doi.org/10.26418/telectrical.v1i2.70662

Irawan, Y., Febriani, A., Wahyuni, R., & Devis, Y. (2021). Water Quality Measurement and Filtering Tools Using Arduino Uno , PH Sensor and TDS Meter Sensor. *Journal of Robotics and Control (JRC)*, *2*(5). https://doi.org/10.18196/jrc.25107

Jáquez, A. D. B., Herrera, M. T. A., Celestino, A. E. M., Ramírez, E. N., & Cruz, D. A. M. (2023). Extension of LoRa Coverage and Integration of an Unsupervised Anomaly Detection Algorithm in an IoT Water Quality Monitoring System. *Water (Switzerland) MDPI*, *15*(7), 1–17. https://doi.org/10.3390/w15071351

Matysik, M., Absalon, D., Janczewska, N., & Woźnica, A. (2025). Detection of changes in water salinity based on patrol monitoring and remote sensing methods. *Desalination and Water Treatment*, *321*, 1–11. https://doi.org/10.1016/j.dwt.2024.100930

Misiurek, K., Olkusi, T., & Zyk, J. (2025). Review of Methods and Models for Forecasting Electricity Consumption. *Review of Methods and Models for Forecasting Electricity Load (Energies)*, *18*(15), 1–27. https://doi.org/10.3390/agriculture15040367

Mustofa, A. (2020). *Pengelolaan Kualitas Air untuk Akuakultur* (N. Kursistiyanto, P. A. Wibowo, R. Rizqi, & G. M. S. W. D. Pratama, Eds.; 1st ed.). UNISNU Press.

Navarrete, M. C., Díaz-Herrera, N., & González-Cano, A. (2024). Salinity Measurement with a Plasmonic Sensor Based on Doubly Deposited Tapered Optical Fibers. *Sensors*, *24*(15), 1–18. https://doi.org/10.3390/s24154957

Parra, L., Tudela, S. V., Carrasco, D., Sendra, S., & Lloret, J. (2023). Low-Cost Microcontroller-Based Multiparametric Probe for Coastal Area Monitoring. *Sensors*, *23*(4), 1–19. https://doi.org/10.3390/s23041871

Purba, N. P., Faizal, I., Valino, D. A., Kang, H. S., Sugianto, E., Martasuganda, M. K., Abimanyu, A., Bratasena, T., Zenyda, K. S., Prayogo, N., Ramdhani, F., & Khan, A. M. A. (2023). Development of autonomous multi-sensor ocean monitoring instrument designed for complex archipelagic waters. *International Journal of Environmental Science and Technology*, *20*(10), 1–10. https://doi.org/10.1007/s13762-023-04772-5

Ramadhan, H. P., Kartiko, C., & Prasetiadi, A. (2020). Monitoring Kualitas Air Tambak Udang Menggunakan Metode Data Logging. *Jurnal Teknik Informatika Dan Sistem Informasi*, *6*(1), 102–114. https://doi.org/10.28932/jutisi.v6i1.2365

Saraswati, I., Himawan, G., Wiryadinata, R., Ramadhani, A., Haryanto, H., Franata, N., Yudono, M. A. S., & Erlindriyani, R. V. (2025). Prototype system for turbidity and TDS measurement of refill drinking water using Arduino microcontroller. *Teknika: Jurnal Sains Dan Teknologi*, *21*(01). https://doi.org/10.62870/tjst.v21i1.30486

Sharma, S., & Bhatt, R. (2023). Monitoring Water and Soil Salinity across Mentor Marsh to Investigate Their Temporal and Spatial Variability. *Water (Switzerland)*, *15*(23), 1–17. https://doi.org/10.3390/w15234172

Suminten, N., Arjo, S., Roza, L., & Fitriana, A. (2021). Perbandingan Konsentrasi Larutan Garam dan

Air Kelapa Terhadap Nilai Konduktivitas Listrik. *JPF (Jurnal Pendidikan Fisika) FKIP UM Metro*, *9*(2), 164–171. https://doi.org/10.24127/jpf.v9i2.4067

Toruan, F. L., & Galina, M. (2023). Internet of Things- Based Automatic Feeder and Monitoring of Water Temperature, PH, and Salinity for Litopenaeus Vannamei Shrimp. *Jurnal Teknik Elektro, Teknologi Informasi Dan Komputer (ELTIKOM)*, *7*(1), 9–20. https://doi.org/10.31961/eltikom.v7i1.658

Widharma, I. G. S., & Wiranata, L. F. (2022). *Mikrokontroler Dan Aplikasi* (N. Wahid, Ed.; 1st ed.). Wawasan Ilmu.

Yunarty, Kurniaji, A., Budiyati, Renitasari, D. P., & Resa, M. (2022). Karakteristik Kualitas Air dan Performa Pertumbuhan Udang Vaname (Litopenaeus vannamei) Pola Intensif. *Pena Akuatika : Jurnal Ilmiah Perikanan Dan Kelautan*, *21*(1), 75–88. https://doi.org/10.31941/penaakuatika.v21i1.1871