AN IoT-ENABLED DESIGN FOR REAL-TIME WATER QUALITY MONITORING AND CONTROL OF GREENHOUSE IRRIGATION SYSTEMS
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DESAIN PERANGKAT BERBASIS IoT UNTUK PEMANTAUAN DAN PENGENDALIAN KUALITAS AIR PADA SISTEM IRIGASI RUMAH KACA

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DOI: https://doi.org/10.35633/inmateh-69-39

Keywords: *greenhouse, internet of things, water quality, irrigation system, automation*

ABSTRACT
Because hydroponic plant nutrients are dissolved in the water, water quality management is essential for growing healthy plants. Taking care of the total dissolved solids (TDS) and the pH (water acidity) is essential. The purpose of this research is to create an IoT-based water quality monitoring device. The average TDS after 30 days of automation with an Arduino UNO was 1162.82 ppm, and the gadget kicked on the nutrient pump whenever the TDS fell below 1000 ppm or the EC fell below 2. The mechanism self-adjusts the pH when it falls below 5.5 or rises above 6.5, with a mean of 6.17.

ABSTRAK
Karena nutrisi tanaman hidroponik terlarut di dalam air, manajemen kualitas air sangat penting untuk menanam tanaman yang sehat. Menjaga total dissolved solid (TDS) dan pH (keasaman air) sangat penting. Tujuan dari penelitian ini adalah untuk membangun perangkat pemantauan kualitas air berbasis IoT. Rata-rata TDS setelah 30 hari otomatisasi dengan Arduino UNO adalah 1162.82 ppm, dan alat ini akan menyalakan pompa nutrisi setiap kali TDS turun di bawah 1000 ppm atau EC turun di bawah 2. Mekanisme ini akan menyesuaikan pH ketika turun di bawah 5.5 atau naik di atas 6.5, dengan rata-rata 6.17.

INTRODUCTION
Smart farming, which is also called intelligent agriculture, is a way of managing farms that uses information technology like the Internet of Things (IoT), robotics, drones, and artificial intelligence to improve the quantity and quality of agricultural products while reducing the amount of labor needed for farming *(Raj, Appadurai, & Athiappan, 2022).* Producers and decision-makers will be able to evaluate and protect the agricultural sector. They will also be able to fight climate change and improve production with these tools. Through the integration of Internet of Things (IoT), it is expected that farmers can minimize crop failure and increase the quantity and quality of production by measuring environmental conditions on agricultural land by empowering precision agriculture which hopes to optimize, for example, irrigation techniques that are efficient, targeted and have nutrient levels that are in accordance with the needs of plants or feeding that adjusts to the age of livestock and their nutritional needs *(Bodirsky et al., 2022; Pachayappan, Ganeshkumar, & Sugundan, 2020)*. The application of IoT enables the development of smart agriculture that has the vision to collect, process and analyze data at the same time, automate various steps of agricultural procedures and allow for the improvement of overall farm operations and management, so that farmers can make more informed and faster decisions *(Trilles, González-Pérez, & Huerta, 2020)*.

One of the most promising ways to use IoT is to add automation and information technology to a greenhouse. This would allow the greenhouse's condition to be constantly monitored and recorded. The goal is to track and analyze data about plant growth, irrigation, environmental conditions, climate changes, and pest infestations. This data can be easily stored on a server and shared through different channels, like social media or websites *(Ardiansah, Bafdal, Bono, Suryadi, & Husnuzhan, 2021)*. To do this, the IoT application needs to have a constant internet connection in the greenhouse, use microcontrollers and sensors to replace human senses, and record data in real time so that it can be used for further development *(Gondchawar & Kawitkar, 2016)*. Using a greenhouse gives you the chance to control all of the things that affect how plants grow, both by hand and automatically. Automated control can change things like temperature, humidity, air flow, how much light a plant gets, how much food and water it gets, and even the quality of the water *(Bhosure, Bhosure, & Sharma, 2016; Khoa, Man, Nguyen, Nguyen, & Nam, 2019).* Through automation, the data that is collected and stored can be used to predict future trends. This lets the automation device figure out the best way to proceed based on calculations from the past. For plants to grow better and crop yields to be as high as they can be, Indonesia needs to come up with smart agricultural practices to monitor and control the microclimate inside greenhouses and to control the quality of irrigation water before it is delivered *(Bersani, Ruggiero, Sacile, Soussi, & Zero, 2022)*. Because there isn't a good way to monitor and control the water quality in greenhouses, plants get water that hasn't been cleaned. So, the goal of this study is to come up with and implement an automated system that uses the Internet of Things to check and control the quality of irrigation water before it is given to plants in greenhouses.

MATERIALS AND METHODS

When it comes to measuring water, keeping the temperature stable is the most important thing because of how it affects pH and DO measurements. In this situation, the waterproof DS18B20 sensor stands out as a very reliable way to measure the temperature of water. The error rate of this high-tech sensor is well below 2%, which is a very good thing *(Agustin et al., 2022)*. It is especially impressive how accurate it is at normal temperatures. The DS18B20 temperature sensor has a digital sensor with a sophisticated silicon-based internal circuit. It also has a temperature sensor, an analog-to-digital converter, and a place to store data. Because of these technical details, the sensor can do complicated calculations and give accurate readings in the form of actual water temperature values. A pH sensor is used to measure the amount of acidity in water. Its main jobs are to keep an eye on the quality of the water and help aquatic organisms grow. A pH meter's main job, based on a comparison to pure water with a neutral pH, is to measure the amount of hydrogen ions in a solution. On a scale from 0 to 14, the pH value shows how acidic or alkaline something is, with 0 meaning very acidic and 14 meaning very alkaline *(Egbueri, Mgbenu, Digwo, & Nnyigide, 2021)*.

In order to foster optimal growth, nutrient concentration and pH levels must be harmoniously balanced and remain stable over a duration of time, ensuring that the plant consistently receives the requisite amount of nutrients *(Selim, 2021)*. In hydroponic systems, the amount of nutrients in the water decreases over time as the roots use up the nutrients in the water. One such method of measuring nutrients involves gauging PPM (Part per million) or TDS (total dissolved solid), which can be achieved using a Gravity TDS meter. In this instance, the measurement hinges on the electroconductivity of the solution and the calibration of the device *(Hasan, Khandaker, Iqbal, & Kabir, 2020)*. The turbidity is used to measure the level of turbidity in water by looking at how the water looks. It works by measuring the amount of light between two probes and figuring out how much light was picked up by the reader probe. When the light hits particles that are floating in the water, it spreads out, which changes the intensity reading. So, the output voltage of the sensor changes based on how cloudy the water *is (Rafid, Redwan, Abrar, Ahmed, & Pathik, 2019)*.

Methodology

The inputs of the device are measured water quality values from sensors at the top of the tank. The monitoring function of the device is turned on when the water level in the tank reaches a certain level. During the mixing of the solution, the device checks to see if the results of the measurements are still within or outside the pre-set threshold. In the end, the output is used to check the quality of the monitored water by adding the solution until the values match the set point. An Arduino UNO is used to carry out these three steps. The Raspberry Pi SBC also acts as a server that controls the data sent by the microcontroller. This lets users access the monitoring and control data for water quality. The program algorithm starts when water is put into the storage tank and stops when the water reaches a certain level. At that point, the sensor system takes readings to see if the set point has been met or if more treatment is needed. If more treatment is needed, the water is moved to the next storage tank so that the quality can be changed until the water meets the set point. When the TDS value is less than 1000 ppm, an AB Mix solution is added to reach the required TDS value *(Setyawan, Nugrohoa, Febyana, & Pramono, 2022)*. When the pH level is outside of the range of 5.5 to 6.5, an alternative solution is used for the best control *(Ardiansah, Bafdal, Bono, Suryad, & Nurhasanah, 2022)*. As soon as the water quality is good enough for greenhouse plants, it is let out until the storage tank is empty.

The used equipment has a data management server, an automation process device, and four different sensors, including the TDS and EC Sensor (Gravity TDS Meter 1.0), pH Sensor (pH-4502C), Water temperature sensor (DS18B20), and Turbidity sensor. In addition to these, a relay unit is incorporated as a switch, to enable activation or deactivation of the DC motor. The DC motor's primary purpose is to energize the AB Mix solution pump and pH solution. It is important to use a relay because the motor needs a 12v voltage from an extra DC power source to move. When a reading from the TDS sensor or pH sensor doesn't match the set point, the relay gets turned on. This turns on the DC motor connected to the peristaltic pump, which mixes the control solution with the water to reach the set point. Through a serial port, the automation system device connects to the SBC, which acts as a server, and sends water quality monitoring results, the status of the automation system, and the processing time.

Design

The Single Board Computer (SBC) works as a server because it has multiple ways to connect to a communication network. It can connect to a Local Area Network (LAN) using RJ45 or LAN cables, or it can connect wirelessly using WiFi or Bluetooth, giving users a variety of ways to get to their data. MicroSD-based storage media can be used by automation systems to handle large amounts of data in an efficient way.

The TDS and pH sensors used in the experiment can only have analog pins, so they have to be hooked up to a microcontroller. If both sensors are turned on at the same time, there might not be enough DC power, which could cause inaccurate data readings. This lack of power can also happen when the relay is turned on. Since the peristaltic pumps need a voltage of 12V, the relay used cannot make them work. To solve this problem, a step-up converter is built into the system to connect the switching relays to the voltage supply for the pump. With this setup, the pump can move the AB Mix solution and the pH solution into the storage tank.

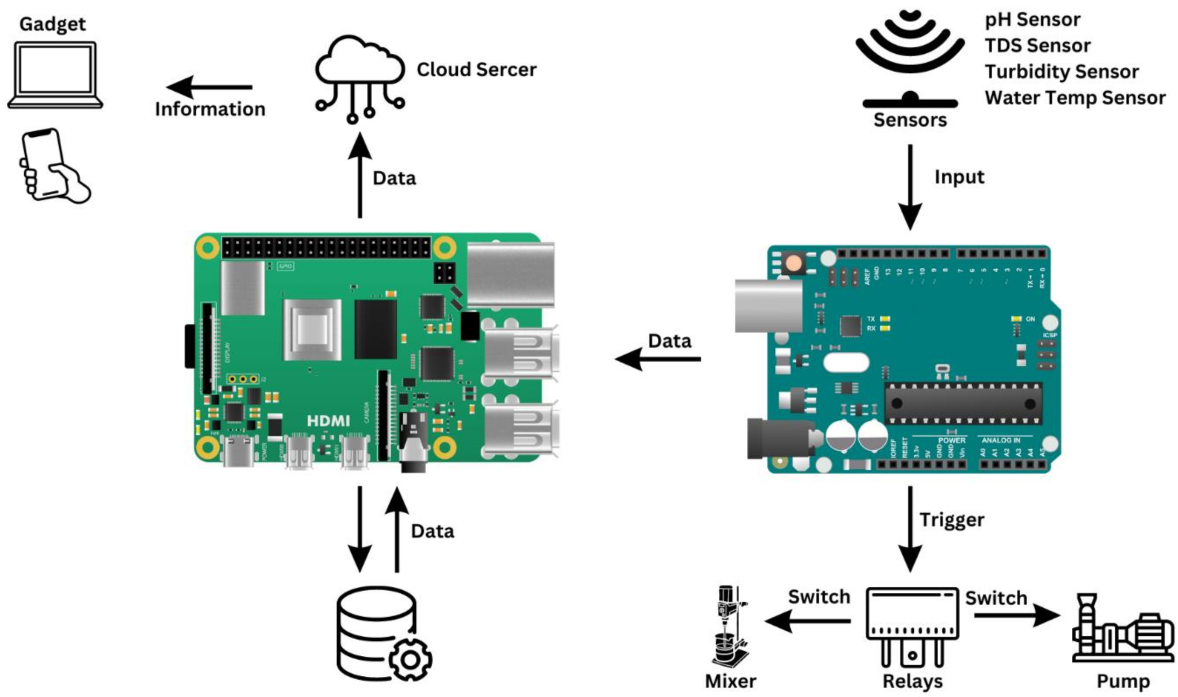


Fig. 1 - Water quality monitoring and control automation system architecture

Design shown in Figure 1 is used to build the water quality automation system. This involves changing the design of the nutrient solution reservoir that is already available in the Unpad ALG Greenhouse. This is done by moving the reservoir lower so that water from the main source of water storage can flow into the system storage tank. On the side of the storage tank are the microcontroller, SBC, and all of the sensors and parts that go with them. Since the two are connected by a USB cable, they are close to each other. The sensor probe, which is used to measure water quality, is in the storage tank. When the water in the tank stops moving, the probe automatically takes measurements. The peristaltic pump, which is an actuator, is placed close to the relay so that it can be fixed faster if there is a problem with how the two are connected. The data about the water quality will be sent through a serial connection in the form of an array. The SBC will receive the data and translate it before putting it in the database. As soon as the data shows that the water is no longer of the right quality, the microcontroller will change the pH and TDS values of the water. The control system will work every six hours. First, water will flow into the storage tank. Then, the water will be checked to make sure it's at the right quality level before it's used for irrigation.

The amount of data that comes out of each iteration depends on the initial measurement of water quality. The bigger the difference between the measurement and the set value, the more procedures are run, which means more data is sent to the database and stored there. In this research, the TDS and pH levels of the water are the most important data points. Other data points, such as temperature and turbidity, add to and strengthen the monitoring results. The pump is set up to dispense the AB Mix, pH Up, or pH Down solutions depending on what is needed. When the set value is reached, the microcontroller tells the relay to change its state, which stops the pump from working. Since the pH sensor used in this study is analog and sends the pH value as a voltage between 0 and 5v, but the pH value is between 0 (extreme acidity) and 14 (extreme alkalinity), it is important to convert the voltage readings sent by the sensor into pH units to make sure the SBC gets the right values *(Mwemezi & Sam, 2019)*. Table 1 shows the algorithm that is used for the conversion process.

Table 1

Pseudocode for checking water ph value

```
load ph library
connect to ph sensor
if (serial port) ≠ ready
 recheck
end if

while (true)
 while (samples <= 10)
  read bitvalue from water
 end while

 voltage = 5 / (1024.0 * (bitvalue/samples))
 ph = -5.7 * voltage + 22.74

 if (pH < 5.5)
  pHUp Pump ON
 else if (pH > 6.5)
  pHDown Pump ON
 else
  pHUP Pump OFF
  phDown Pump OFF
 end if
 read DHT11 humidity in Percent

 send pH data using serial connection
 delay for 60 seconds before continue reading
end while
```

The nutrient content has to be controlled over and over again, just like the pH level, until the TDS value goes over 1000ppm. Before turning on the TDS sensor, all relays must be turned off to make sure that the measurements are accurate and that the data sent to the database isn't messed up. One sign of a drop in voltage is that the indicator light on the automation system is not as bright as it should be.

Table 2

Pseudocode of Nutrient Addition in Water

```
load tds library
get datetime now

if (serial port) ≠ ready
 recheck
end if

while (true)
 water_level = duration * (0.034 / 2)
 if (water_level < 15)
  water pump ON
 else if (water_level > 15)
  water pump OFF
 end if

 get water temp
 get voltage
```

```
tds = (voltage – 55) / 1.75
ec = tds – 500

if (tds < 1000)
 nutrition pump on
 stir water ON
else
 nutrition pump off
 stir water OFF
end if
```

Table 2 shows how the AB Mix nutrient solution is used to control the amount of nutrients in the water reservoir. When the TDS value is different from the set point, the automation system will turn on both nutrient solution pumps A and B. Once the flow of nutrient solution is done, the automation system will turn off the relay connected to the nutrient pump and turn on the relay connected to the DC Fan for 1 minute. This will make sure that the AB Mix nutrient solution and the water in the reservoir are thoroughly mixed. To connect the relay to the DC Fan, which runs on a voltage of 12v, you need a 12v voltage adapter. Also, the water quality monitoring and control automation system can collect sensor data like pH, TDS, water temperature, turbidity, and monitoring time. By adding the Real Time Clock (RTC) module, the automation system can get measurement time data, which makes it easier to plan when to supply water. Adding the RTC module to the automation system gives it an extra benefit, making it better for controlling when water is supplied.

Construction

The microcontroller sends data to the serial port in the form of an array, which is easy for the application to understand and decode. This includes readings of the water tank level, TDS value regulation (if the value is outside the set-point), pH value regulation (if the value is outside the set-point), and a final reading when all stages are finished. The reason for sending data one at a time is to speed up the process of reading data from the microcontroller and entering it into the right database column. Through the serial port, the data is sent in this order: Water Temperature, TDS, EC, pH, and Turbidity. If the water meets the parameters that have been set, it goes to the plant. If it doesn't, it goes to a secondary storage tank for more testing. If the TDS value is wrong, the AB Mix solution pump starts working. If the pH value is wrong, either the pH Up or pH Down pump starts working. If the TDS and pH values don't match the set points, the system will first turn on the AB Mix solution pump until the values match, and then it will turn on the pH solution pump. A 12v DC Fan is built in to make sure that the added solution and the water in the storage tank mix evenly. Once the mixing is done, the system will use the sensor to take another reading of the TDS and pH levels of the water to see if they match the set-points. If the set points don't match up with the parameters, the control process will start over and end with the last reading.

RESULTS AND DISCUSSIONS

Study by *(Soerya, Bafdal, & Kendarto, 2020)* on how rainwater fertigation technology and hydroponics can be used in a greenhouse, a system has been made to monitor and control the quality of irrigation water. The study showed that watering tomato plants with rainwater can lead to a harvest weight of 2.45 KG per plant, with 19.01 liters of water used and an impressive efficiency of 94.07 KG/m^3. These results show that crop yields could be increased by making sure that the quality of the water matches the needs of the plant *(Shah & Wu, 2019)*.

Evaluation of TDS Sensors

In the experiment, the TDS sensor was put through ten tests with different TDS values. The TDS sensor was used to measure the TDS value of the water. Then, the results from the TDS-3 Handheld Meter, a measuring device with an accuracy of 2.00%, were compared to those from the TDS sensor. The datasheet for the TDS Gravity sensor says that the maximum reading is 1000ppm, but during testing, the TDS sensor was able to measure TDS values of up to about 1200ppm. When compared to the measuring instrument, the TDS values from the sensor were wrong for measurements above 1200ppm. Table 3 shows the test results for the TDS sensor, which had a measurement error of 5.02% when compared to the measuring tool. From these results, we can conclude that the TDS sensor is a reliable and accurate way to measure the TDS value in this research. In ten tests, the difference between measurements was only 70.00ppm, and the average error was 30.30ppm. This shows that the sensor works well, as it is on par with the TDS-3 Handheld Meter, a measuring device made specifically for measuring TDS values in water.

Table 3

Testing results of TDS sensor

No	TDS meter	TDS Sensor	Difference	Percentage Error
1	324.00	304.00	20.00	6.10%
2	414.00	380.00	34.00	8.20%
3	482.00	452.00	30.00	6.10%
4	536.00	536.00	0.00	0.00%
5	579.00	605.00	26.00	4.40%
7	650.00	715.00	65.00	10.00%
8	721.00	791.00	70.00	9.40%
9	936.00	986.00	50.00	5.30%
10	1020.00	1028.00	8.00	0.70%
		Mean	30.30	5.02%

During the evaluation process, the same steps are used to automatically measure TDS levels. First, a peristaltic pump moves water into the holding tank until it's full. Then, a TDS sensor and instrument are used to measure how much TDS is in the water. After the initial readings are taken, the AB Mix solution is poured into the water reservoir and stirred well. This process of mixing and stirring is done nine times, and after each time, the TDS level is measured again.

Putting the pH Monitor to the Test

The pH sensor goes through a similar process in which the measurement results are looked at ten times with different pH values. The pH-009i Handheld Meter, which has an accuracy of 0.1, is used to compare the pH4502c sensor with the pH-009i Handheld Meter. Even though litmus paper is an alternative way to test, it is not very accurate at 1. The datasheet says that the pH4502c sensor has a level of accuracy of 0.50. By looking at the test results in Table 4, we can see that the pH sensor can give accurate measurements with a measurement error of only 4% when compared to the measuring instrument. This proves that it could be used in this study. Also, the difference between the ten tests was no more than 0.41, and the average measurement error was 0.25. This shows that the pH sensor's performance is very close to that of the pH-009i Handheld Meter, which is used to measure the pH of water.

Table 4

Testing results of pH sensor

No	pH meter	pH4502C Sensor	Difference	Percentage Error
1	7.2	7.39	0.19	2.60%
2	7.1	6.85	0.25	3.50%
3	4.2	4.03	0.17	4.00%
4	4.5	4.09	0.41	9.10%
5	8.1	7.84	0.26	3.20%
7	8.2	8.57	0.37	4.50%
8	8	7.93	0.07	0.90%
9	7	7.28	0.28	4.00%
10	6.7	6.42	0.28	4.20%
		Mean	0.25	4.00%

In the evaluation process, the same method is used over and over to automatically measure the pH level of the storage tank. A peristaltic pump fills the tank with water until it is full, and then a pH sensor and measuring device are used to measure the pH. After the measurements are written down, the pH Up or pH Down solution is added to the water tank and the water is stirred very hard nine times to make sure it is all the same. After that, pH values are measured again.

Irrigation Water Quality Monitoring Automation Data: A Descriptive Statistical Study

The effectiveness of an automation system can be judged by how well it can control a number of parameters, such as the TDS and pH values of water, based on pre-set points. The monitoring and control automation system for water quality was built, and its performance was measured over the course of a month.

Every six hours, data was collected and put in a database so that it could be used later for statistical analysis. Also, descriptive statistical analysis was done on the data collected about the quality of the water when it went into the tank. The results are shown in Table 5.

Table 5

Descriptive statistics when water enters the tank

	Temperature	TDS	EC	pH
Total	3209.00	49937.00	23.00	807.72
Mean	27.15	423.15	0.20	6.84
Median	27.00	398.00	0.00	6.72
Modus	27.00	409.00	0.00	6.48
STDev	0.82	212.22	0.52	0.68
Max	29.00	1662.00	3.00	10.44
Min	25.00	103.00	0.00	5.03
Range	4.00	1559.00	3.00	5.41

Table 5 shows that when water is put into the tank, the average TDS value is 423.15 ppm, which is not enough to meet the plant's requirement of 1000ppm, and the standard deviation is 212.22. This means that the water's electrical conductivity and TDS level aren't good enough, so AB Mix liquid fertilizer needs to be used to raise the TDS level. On the other hand, the average pH value of the water going into the tank was found to be 6.84 0.68. This means that the pH level is still higher than the expected range of 5.50 to 6.50. As a result, the pH Down pump runs more often than the pH Up pump. Still, as the table shows, the pH value of 6.48 is the one that is seen most of the time.

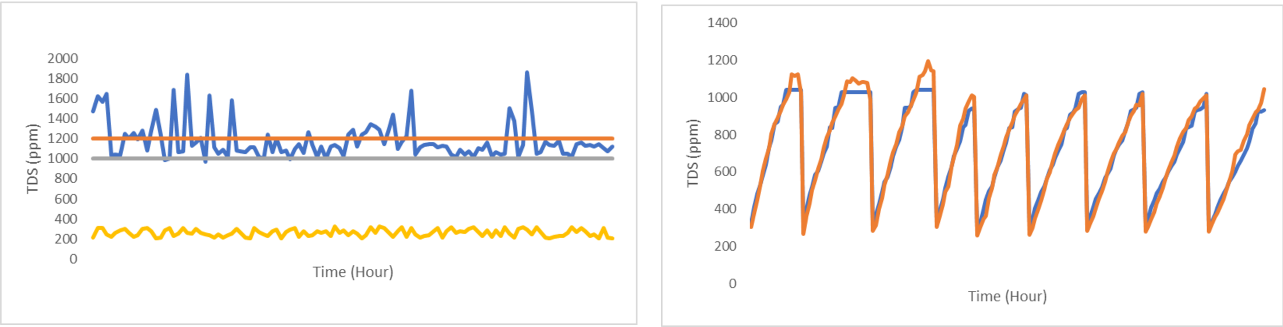
Based on the calculations shown in Table 6, descriptive statistics were used to look at the TDS and pH levels after the automation system had finished controlling them. The average TDS value of 1181.30 183.68 ppm is higher than the goal of 1000 ppm, so the expected goal was met. But because several sensors were being used at the same time and there were problems with the power supply, the maximum TDS value of 1870.00ppm was reached, which caused sensor readings to be wrong. This problem could be solved by connecting only one sensor to the microcontroller, which would eliminate worries about running out of power. Regarding the pH control, the average value of 6.17 0.30 shows that the pH control did not produce the expected results. This could be due to a less-than-ideal pH solution, an uneven mix of water and pH solution, or the effect of the AB Mix solution on the pH value. In the future, research will be done to find out what effect AB Mix solution has on pH. Also, the maximum pH value of 7.21 is lower than the value of 10.44 that was seen when water was put into the tank. This shows that the pH solution can lower pH, but has not yet reached the set point of 5.5 to 6.5.

Table 6

Descriptive statistics when control is complete

	Temperature	TDS	EC	pH
Total	3180.00	138211.00	238.00	722.44
Mean	27.18	1181.30	2.03	6.17
Median	27.00	1127.00	2.00	6.18
Modus	27.00	1046.00	2.00	6.12
STDev	0.79	183.68	0.29	0.30
Max	29.00	1870.00	3.00	7.21
Min	25.00	973.00	1.00	5.11
Range	4.00	897.00	2.00	2.10

Based on all of the TDS measurement data, the results show that the automation system is able to raise the TDS value until it reaches the set point of 1000 ppm. The automated system for adding nutrients has shown that it can raise the levels of nutrients up to the limit that was set. It's important to remember that the 1000ppm threshold was set based on the sensor's ability to measure TDS, which can only read up to 1000ppm with a 10% tolerance, according to the datasheet for the sensor. But a look at the sensor reading after the experiment has shown that it has reached 1100ppm. Figure 2a shows that out of the 118 processes that were run, 36 had measurement values that were higher than 1200ppm. This shows that the automation system is good at measuring and controlling the TDS and pH of water. But it's important to know that high-value spikes can happen because of sensor interference, like a drop in voltage or dirty sensors.

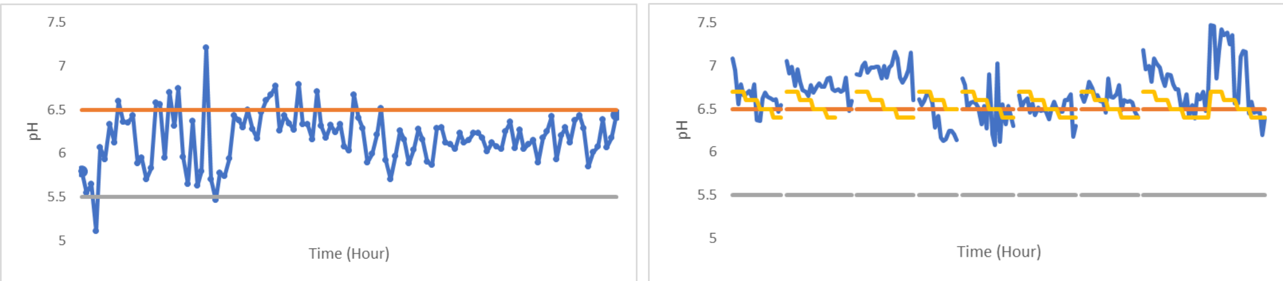


(a) **(b)**

Fig. 2 – (a) Results of TDS control automation (b) Movement of TDS value from flow to process completion

Figure 2a shows that there was a sharp surge in the measurements results, with a worrying high of 1800ppm. Such wrong readings shouldn't have happened, but our thorough analysis has found several reasons why they did: (1) Sensor readings that change like the voltage, (2) Errors caused by loosely connected jumper cables that lead to intermittent power supply and, as a result, less accurate measurements, and (3) DC fans that don't work right and don't mix the solution well, which leads to inaccurate readings of TDS and pH values. It is important to remember that if you don't mix the AB Mix nutrient solution with water well enough, the solution can settle in the water, which causes the TDS values of the next nutrients to be high.

Figure 2b portrays the automation process of infusing AB Mix nutrients and gauging the TDS value, commencing from the water's entry into the system until the culmination of the control process. The precision of the TDS sensor measurements is demonstrated through a comparison with data collected from the TDS-3 Handheld Meter, encompassing the period from water entry into the storage tank to the completion of the control process. A peristaltic pump flows AB Mix nutrient solution for a trifling three seconds, after which a DC Fan blends the solution homogeneously. The ensuing measurements are methodically translated into a graph showcasing the meticulous course of AB Mix nutrient solution infusion, culminating at the desirable 1000ppm concentration, with the concurrent pH control process concluding after a 12-minute runtime.



(a) **(b)**

Fig. 3 – (a) Results of pH control automation (b) Movement of pH value from flow to process completion

Figure 3a depicts the procedural steps taken post the completion of water pH control. As the AB Mix nutrient solution is gradually introduced, the pH measurement records a corresponding decline. In the event that the water pH falls beyond the predetermined set-point, the pH Down pump is initiated to initiate the water pH control procedure. Although the pH sensor probe is capable of determining the acidity of the water, it necessitates calibration before use. Upon conducting several experiments, a pH value of 6.70 is recorded for the water in the holding tank using a Handheld Meter pH measuring device, which decreases to 6.40 after the incorporation of AB Mix nutrient solution.

Graph at Figure 3b does a good job of showing the changes that happen during the control process. This happens because the pH sensor reading is messed up when the TDS sensor is working at the same time. Along with interference from the TDS sensor, changes in pH values can be caused by: 1) Probes that get dirty over time, 2) putting a pH probe next to a TDS sensor, which causes a voltage drop in the pH sensor, 3) putting pH probes above the surface of the water while measuring, and 4) other things *(Rastegari et al., 2023).*

CONCLUSIONS

The findings of this study led the researchers to the conclusion that the instrument that was developed has the capability of automatically reading water quality and updating data on a database. This data includes information on parameters such as temperature, total dissolved solids (TDS), electrical conductivity (EC), pH, and turbidity, as well as the process that was carried out. The automation device for adjusting TDS and pH can function based on predetermined setpoints if those points are used. With an average TDS result of 1162.86 ppm and an average pH value of 6.174 when the process is complete, the nutrient pump will turn on automatically when the TDS value drops below 1000 ppm, and the pH balancing pump will turn on when the pH rises above 6.5. In total, the process will produce an average TDS result of 1162.86 ppm and an average pH value of 6.174.

ACKNOWLEDGEMENT

We would like to take this opportunity to thank the Rector of Universitas Padjadjaran, the Directorate of Research and Community Service, and the Directorate of Finance and Treasury of Universitas Padjadjaran for granting me the chance to receive a scholarship and carry out research as part of the Unpad Doctoral Dissertation Research scheme with contract number 1595/UN6.3.1/PT.00/2021. I am extremely grateful for this opportunity.

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