DEVELOPMENT OF IoT BASED AUTOMATED AQUAPONICS SYSTEM FOR WATER QUALITY MONITORING AND CONTROL

By

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THESIS

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CHAPTER IV
RESULTS AND DISCUSSION

An IoT based automated aquaponics system for water quality monitoring and control was developed and tested. Different water quality parameters, including, dissolved oxygen, pH, water temperature, EC, ammonia, and nitrate were monitored and controlled in relation to their impact on plant and fish growth. The experiment utilized IoT technology to monitor and control critical water quality parameters and environmental factors in real time. Additionally, microclimate measurement, biometric parameters of crop were observed and evaluated. In this study, palak was cultivated for a period of 80 days in the developed automated aquaponics system. The yield data for palak and fish at the end of the experiment were analyzed. The experiment was conducted inside a naturally ventilated polyhouse at the KCAEFT campus in Tavanur, Kerala, ensuring a controlled environment for optimal growth of both fish and plants.

4.1. DESIGN AND DEVELOPMENT OF AN IoT BASED AUTOMATED AQUAPONICS SYSTEM

The development and implementation of the IoT-based automated aquaponics system successfully achieved its objectives by integrating aquaculture and hydroponics with real-time monitoring and automation.

4.1.1 Design of aquaponics system

The aquaponics system was designed to meet the requirements for supporting 48 plants by carefully selecting and integrating its components. The aquaponics system has been built and run functionally and adequately as shown in Plate 4.2. Plate 4.3 illustrates the arrangement of components and circuits, which collectively form the automation and IoT system. Various parameters selected are explained under the following subheads.

4.1.1.1 Selection of grow bed and fish tank

A grow area of 1 m² was selected for 48 plants. To provide nutrients to this grow area, a 500 L fish tank was used, following the 1:2 ratio recommended by Rakocy (2012).

Fish tank volume: Grow bed area= 1:2 = 0.5 m^3: 1 m^2

This design facilitates efficient nutrient cycling and maintains optimal water-to-plant ratios, ensuring balanced conditions for both plant and fish growth. The adoption of this configuration aligns with the established principles of aquaponics system design and supports sustainable and productive operations.

4.1.1.2 Pump selection and water circulation

The total head of the aquaponics system was calculated by considering the static head, frictional losses, and minor losses. The vertical height that the water needed to be lifted was 2 m, and the system used a 2.5 m long pipe with a diameter of 25 mm. The frictional losses through the pipe were calculated as 0.2 m, while the minor losses, including elbows and fittings, contributed an additional 0.5 m. This resulted in a total head of 2.7 m for the system. So, the pump selected with a total head of 3.5 m.

Total head of system= 2.7 m

Total head of selected pump= 3.5 m

The selected pump meets the water requirements for 48 plants while ensuring proper filtration and nutrient delivery, promoting healthy plant growth, adequate aeration, and overall system balance.

4.1.1.3 Flow rate to the system

A flow rate of 90-120 L h^{-1}, as recommended by Endut *et al.* (2009), was adopted for the system to ensure optimal water circulation and nutrient delivery.

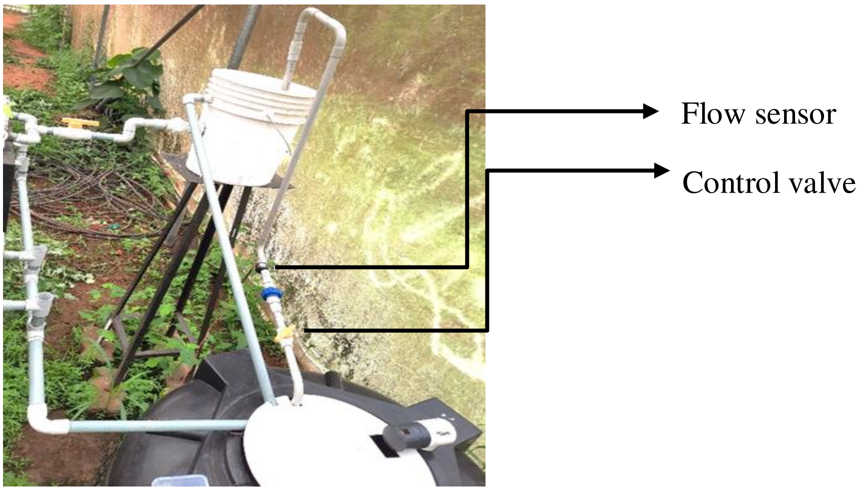


Plate.4.1 Installation of flow sensor and control valve

This flow rate was regulated using a control valve and monitored continuously with a flow sensor installed downstream of the valve (Plate 4.1). The setup ensured consistency and efficiency in maintaining the desired flow rate.

4.1.1.4 Spacing of plants

The grow bed in the aquaponics system utilized channels for plant cultivation, providing a total growing area of 1 m^2. To optimize plant growth and nutrient absorption, the plants were spaced 15 cm apart within rows as recommended by Spehia *et al.* (2022), with a row spacing of 25 cm.

Width of frame= 150 cm

Number of NFT channels= 6

$$\text{Row spacing} = \frac{150}{6} = 25\ cm$$

Plant spacing= 15 cm

This configuration ensured adequate space for root expansion while allowing efficient delivery of nutrient-rich water through the NFT channels. The spacing and design contributed to uniform nutrient distribution and optimal plant health, supporting the overall efficiency of the system.

4.1.1.5 Fish stocking density

For a 500 L tank and a water requirement of 20 litres per fish, 25 fish were selected. Tilapia was chosen as the fish species due to its resilience, fast growth, and adaptability to aquaponics systems. As recommended by Rahmatullah *et al.*, 2010,

$$\text{Stocking density} = \frac{\text{Fish } \boldsymbol{tank\ volume\ (litres)}}{\boldsymbol{Water\ requirement\ of\ one\ fish(litres)}}$$

$$= \frac{500\ L}{20\ L}$$

=25 fishes

Andriani *et al.* (2017) highlighted that maintaining an appropriate stocking density is crucial in aquaponics systems, as higher densities can lead to increased competition for oxygen and space, potentially reducing fish welfare and growth rates. Moreover, excessive stocking density negatively affects water quality by elevating ammonia and nitrate concentrations, which in turn impacts plant productivity. By maintaining a balanced fish-to-water ratio, this system supports optimal fish health while ensuring efficient nutrient cycling, contributing to higher plant productivity and overall system stability.

4.1.1.6 Fish feeding schedule and quantity

The fishes were fed twice a day, with the amount of feed determined as a percentage of fish weight, which was 2.5% of the total fish weight to ensure optimal growth and health, as recommended by Shaw *et al.* (2022).

Average fish weight is 60 grams (for 25 fish), the total fish biomass would be:

$$60 \text{ g} \times 25 = 1500 \text{ g} = 1.5 \text{ kg}$$

Therefore, the total amount of fish feed required daily would be:

$$1500 \text{ g} \times 2.5\% = 35 \text{ g}$$

A slider mechanism was used to ensure the correct quantity of feed delivery. Each week, the fishes were weighed, and the feed amount was adjusted weekly to match 2.5% of their total body weight. This ensured that the fish received adequate nutrition as they grew.

Plate 4.2 Aquaponics system

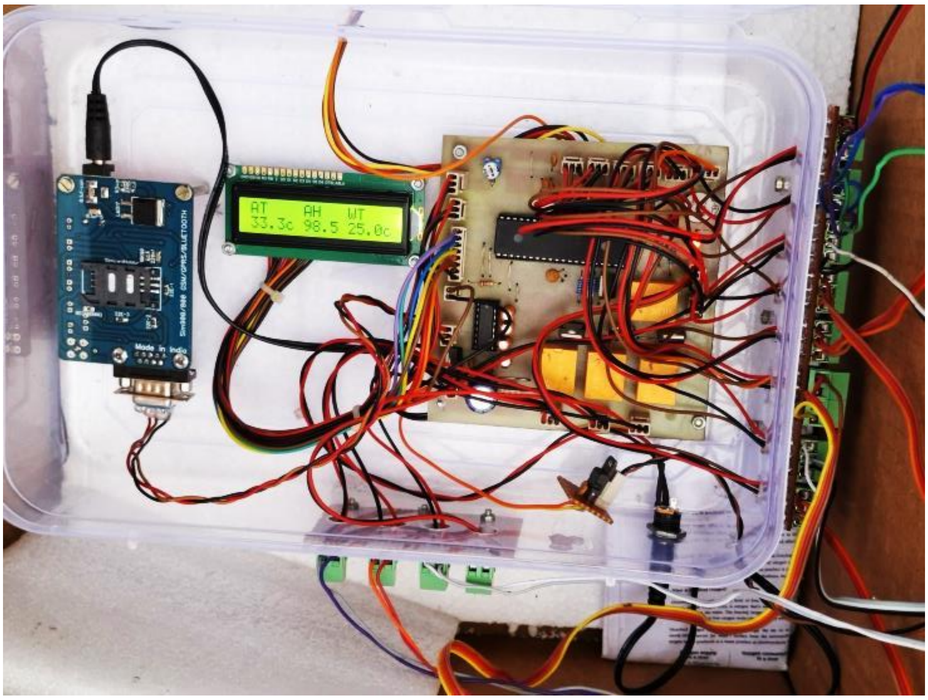


Plate 4.3 Automation circuit

Solenoid valve from water tank

Solenoid valve from pH buffer solution tank

Plate 4.4 Actuators (solenoid valves)

This design ensures a balanced and continuous flow of nutrient-rich water between the fish tank and grow bed, promoting healthy plant growth, maintaining water quality, and supporting fish health. The integration of these components created a well-balanced system where fish waste provides nutrients for plants, plants help purify the water, and the pump maintain circulation, achieving a sustainable and efficient aquaponics system.

4.1.2 Calibration of sensors

Calibration of sensors is a critical process to ensure accurate and reliable measurements in an IoT-based aquaponics system. By aligning sensor readings with standard reference values, the system can effectively monitor key water quality parameters such as pH, dissolved oxygen, temperature, and water level. Proper calibration minimizes errors and enhances the system's ability to maintain optimal conditions for fish and plant growth.

4.1.2.1 Calibration of DHT22 Temperature and Humidity sensor

Temperature readings were recorded using the DHT22 sensor and a dry bulb thermometer at the same time. Calibration curve was developed by plotting the dry bulb thermometer readings against the DHT22 sensor readings, as shown in Fig 4.1. From this plot, a calibration equation was derived (Eq. 4.1):

$$y=0.9199x+ 0.989 \qquad \text{Eq. 4.1}$$

where, y represents the corrected temperature, and x is the DHT22 sensor reading.

The R^2 value of 0.9175 demonstrates a strong correlation between the sensor and reference readings, confirming the reliability of the DHT22 sensor after calibration.

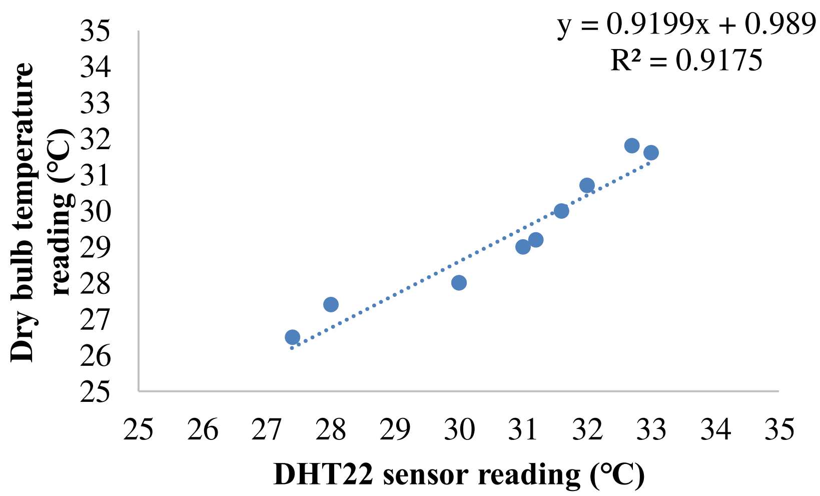


Fig. 4.1 Calibration curve of DHT22 temperature sensor

Similarly, relative humidity (RH) readings were recorded using the DHT22 sensor and a hygrometer. A calibration curve was generated by plotting the hygrometer RH readings against the DHT22 sensor readings, as shown in Fig 4.2. From this plot, a calibration equation was derived (Eq. 4.2):

$$y=0.8236x+9.1719 \qquad \text{Eq. 4.2}$$

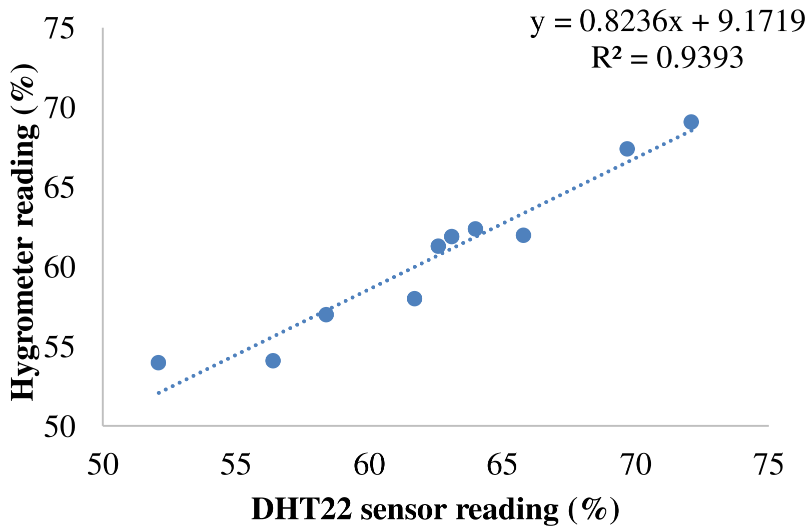


Fig. 4.2 Calibration curve of DHT22 humidity sensor

4.1.2.2 Calibration of DS18B20 water temperature sensor

Water temperature readings were recorded using the DS18B20 sensor and a thermometer at the same time. Calibration curve was developed by plotting the dry bulb thermometer readings against the DS18B20 sensor readings, as shown in Fig 4.3. From this plot, a calibration equation was derived (Eq. 4.3):

$$y=0.9605x+ 0.0676 \qquad \text{Eq. 4.3}$$

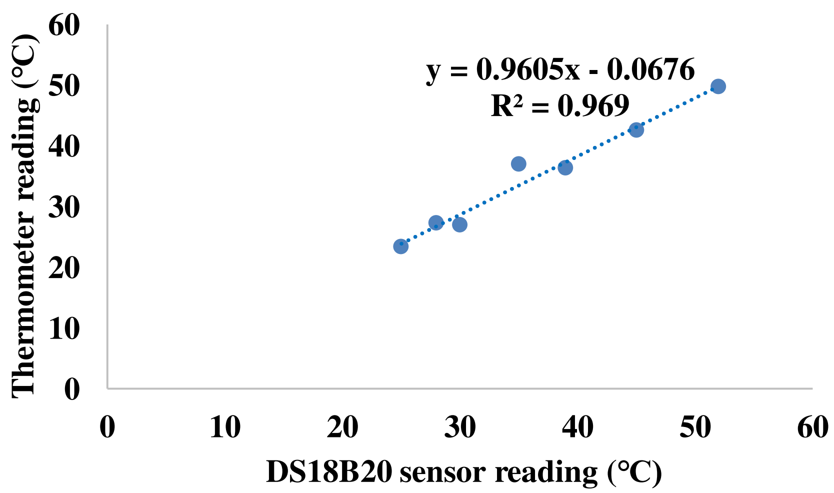


Fig. 4.3 Calibration curve of DS18B20 water temperature sensor

4.1.2.3 Calibration of pH sensor

pH readings were recorded using the pH sensor and a pH meter at same time. Calibration curve was developed by plotting the pH meter readings against the pH sensor readings, as shown in Fig 4.4. From this plot, a calibration equation was derived (Eq. 4.4). pH calibration results were found to be consistent with those reported in Pramono *et al.* (2023).

$$y=0.7314x+ 1.7632 \qquad \text{Eq. 4.4}$$

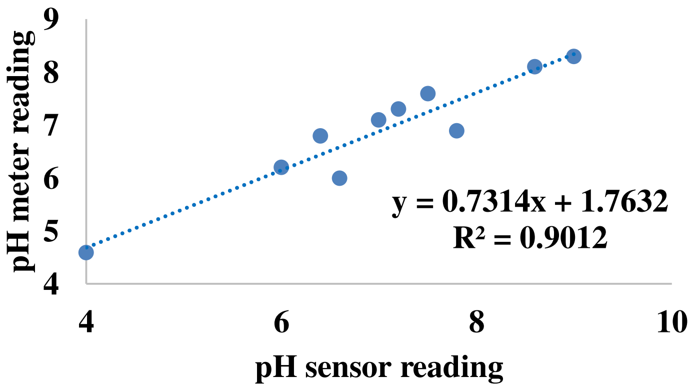


Fig. 4.4 Calibration curve of pH sensor

4.1.2.4 Calibration of EC sensor

Simultaneously, EC readings were recorded using the EC sensor and an EC meter. Calibration curve was developed by plotting the EC meter readings against the EC sensor readings, as shown in Fig 4.5. From this plot, a calibration equation was derived (Eq. 4.5):

$$y=1.0458x+ 0.1999 \qquad \text{Eq. 4.5}$$

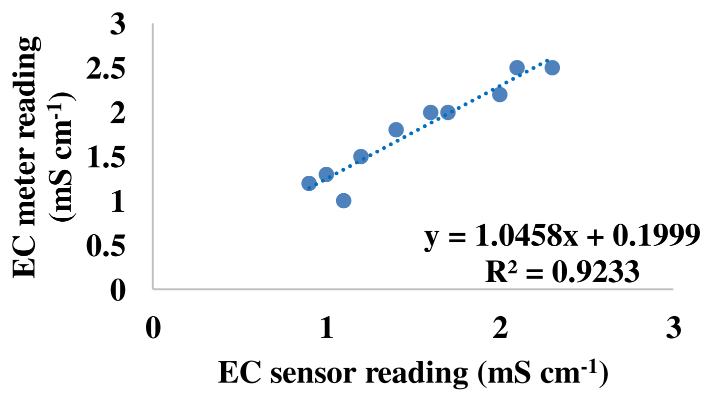


Fig. 4.5 Calibration curve of EC sensor

4.1.2.5 Calibration of DO sensor

Dissolved oxygen readings were recorded using the DO sensor and a thermometer at same time. Calibration curve was developed by plotting the thermometer readings against the DO sensor readings. DO decreases as water temperature increases as shown in Fig 4.6. From this plot, a calibration equation was derived (Eq. 4.6). The R^2 value of 0.9447 demonstrates a strong correlation between the sensor and reference readings, confirming the reliability of the DO sensor after calibration.

$$y = -13.012x + 129.14 \qquad \text{Eq. 4.6}$$

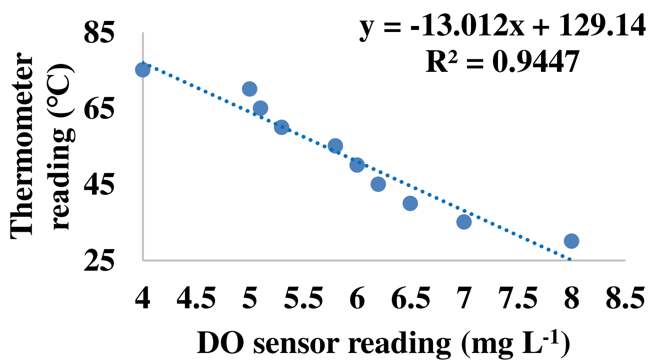


Fig. 4.6 Calibration curve of DO sensor

4.1.2.6 Calibration of ultrasonic water level sensor

Water level readings were recorded using the ultrasonic sensor and a scale. Calibration curve was developed by plotting the scale readings against the ultrasonic sensor readings, as shown in Figure 4.7. From this plot, a calibration equation was derived (Eq. 4.7):

$$y = 0.979x - 0.7171 \qquad \text{Eq. 4.7}$$

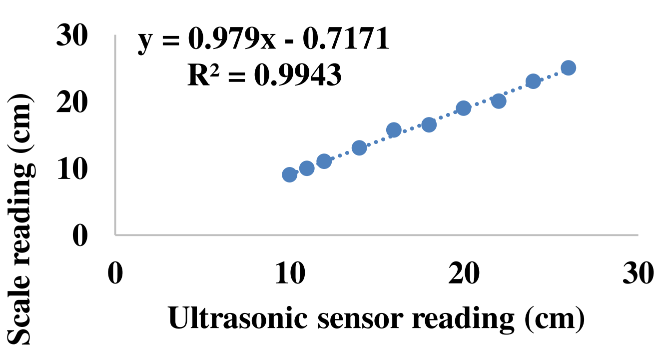


Fig. 4.7 Calibration curve of Ultrasonic water level sensor

4.2 EVALUATION OF THE SYSTEM BASED ON WATER QUALITY PARAMETERS

4.2.1 Performance of the IoT system for monitoring and control of water quality

The experiment was conducted inside the naturally ventilated polyhouse during May 30 to August 30, 2024. The ability of the developed IoT system to monitor (DO, pH, air temperature, air humidity, water temperature, water level, EC, light intensity, flow rate, and flow amount) and control (DO, pH and water temperature) water quality parameters were checked and the results are explained under the following subheads.

4.2.1.1 Monitoring using LCD display

The aquaponics system was designed to monitor and display critical parameters, ensuring efficient operation and real-time management. Parameters such as air temperature, relative humidity, water temperature, pH, water level, electrical conductivity, light intensity, dissolved oxygen, flow rate, and flow amount were continuously recorded and displayed on an LCD screen. The display, with black text on a yellow backlight, provided clear visibility of the monitored values. Before displaying these parameters, the system verified the SIM status, network connectivity, and GSM modem status to ensure proper functionality, as shown in Plates 4.5, 4.6, and 4.7.

Subsequently, the parameters were displayed in a sequential manner, categorized for better clarity. Air temperature, relative humidity, and water temperature were shown first (Plate 4.8), followed by pH, water level, and EC (Plate 4.9). Light intensity and dissolved oxygen (Plate 4.10) and flow rate with flow amount (Plate 4.11) were displayed in subsequent sequences. This setup not only allowed for effective real-time monitoring but also ensured that necessary adjustments could be made promptly to maintain the system's optimal performance. The sequential and categorized display of critical parameters enabled quick identification of any deviations from optimal conditions, ensuring timely corrective actions. The integration of network and GSM status checks further enhanced system reliability, minimizing downtime and supporting continuous, real-time monitoring for efficient aquaponics management.

Plate 4.5 Modem status

Plate 4.6 Sim status

Plate 4.7 Network status

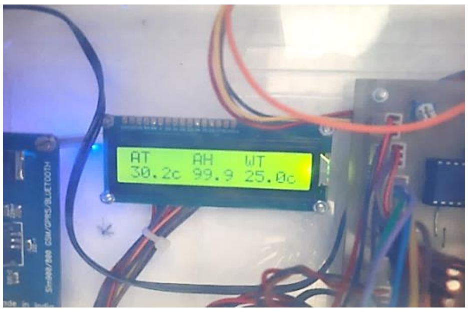


Plate 4.8 Display of air temperature, air humidity, and water temperature

Plate 4.9 Display of pH, water level, and EC

Plate 4.10 Display of light intensity, and dissolved oxygen

Plate 4.11 Display of flow rate, and flow amount

4.2.1.2 Monitoring using GSM by sending SMS

The aquaponics system was equipped with an alert mechanism to ensure continuous monitoring and prompt action. If any parameter deviated from its preset range, the system automatically sent an SMS notification to a pre-registered mobile phone. An Airtel sim was inserted in the GSM and it was linked to the IoT system through proper computer coding. By sending commands, it automatically sent all the information through SMS to the connected Android mobile phone. Screenshots of monitoring using GSM is shown in Fig. 4. 8. The GSM based alert mechanism significantly enhanced the system's responsiveness by providing real-time notifications of parameter deviations. This ensured timely interventions, minimized risks to fish and plant health, and strengthened the overall reliability and autonomy of the aquaponics system.

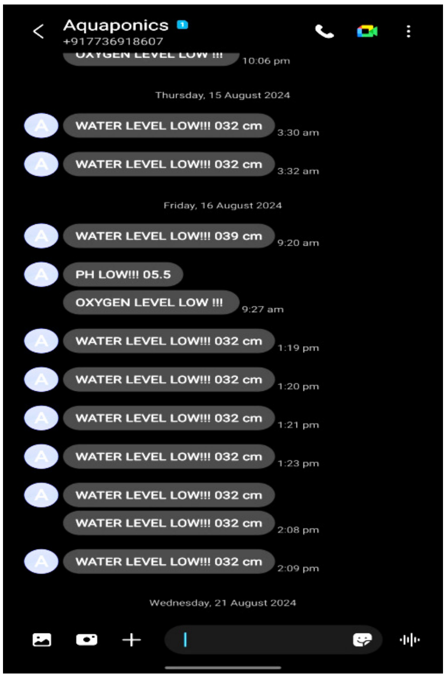
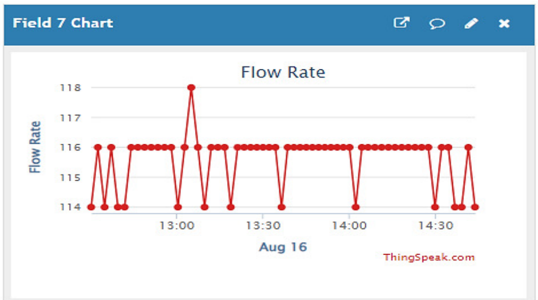


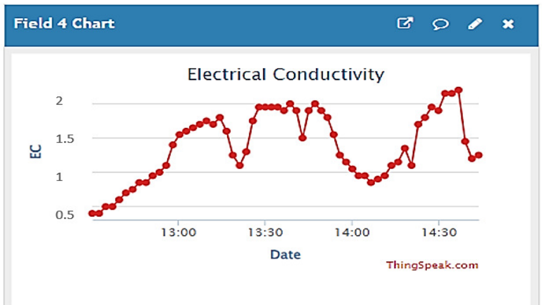
Fig. 4.8 Screenshots of monitoring using GSM by sending SMS

4.2.1.3 Monitoring and analyzing using ThingSpeak

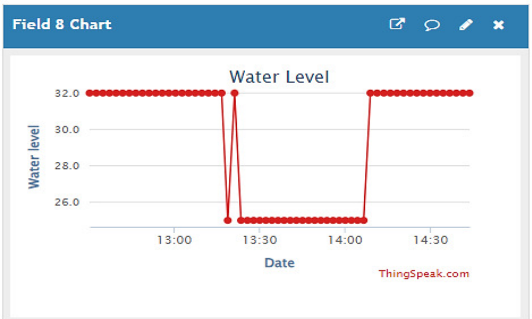
The microcontroller was connected to the ThingSpeak platform via the internet, allowing real-time sensor data to be uploaded. Fig. 4.9 shows the data was visualized on ThingSpeak in the form of graphs, providing an easy way to monitor the system's performance. Additionally, the data could be exported as an excel file for further analysis as shown in Fig. 4.10 and Fig. 4.11. The integration of the ThingSpeak platform enabled effective real-time visualization and historical tracking of sensor data, allowing users to easily detect trends and anomalies in system performance. The ability to export data for further analysis enhanced the system's utility by supporting deeper performance evaluations and informed decision making for aquaponics management.



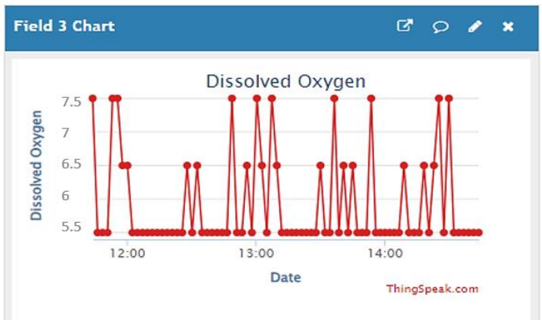
(a)



(b)



(c)



(d)

Fig. 4.9 Monitoring data of a) flow rate, b) EC, c) water level and d) dissolved oxygen from ThingSpeak

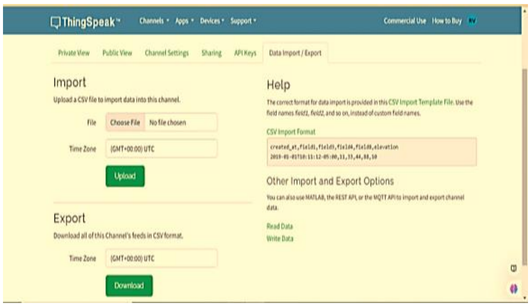


Fig. 4.10 Exporting data from ThingSpeak

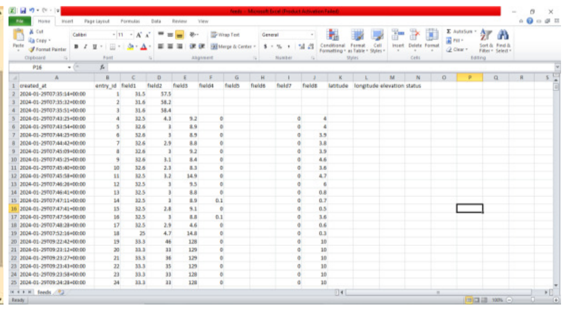


Fig 4.11 Analysis of data using Microsoft Excel

4.2.1.4 Monitoring and controlling of water quality parameters

The automated aquaponics system effectively monitored and controlled deviations in water quality parameters using actuators.

a) Monitoring and controlling of dissolved oxygen

The system was programmed to trigger corrective actions when the DO level dropped below the threshold of 5.5 mg L^{-1}. An instance of this process is illustrated in Plate 4.12, where the display showed a reduced DO level of 4 mgL^{-1}. Upon detecting the low DO level, the system generated an alert (Plate 4.13) and promptly sent a notification via SMS to the operator (Plate 4.14).

Simultaneously, the aerator was activated to replenish the dissolved oxygen in the water (Plate 4.15). This automated response ensured that the DO levels were quickly restored, preventing stress to the aquatic organisms and maintaining the system's balance.

Plate 4.12 Display showing DO 4 mg L^{-1}

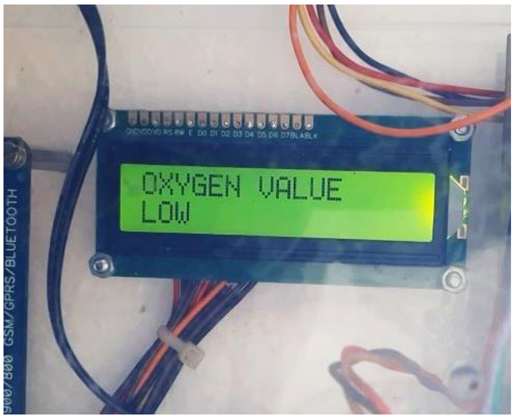


Plate 4.13 Alert showing DO low

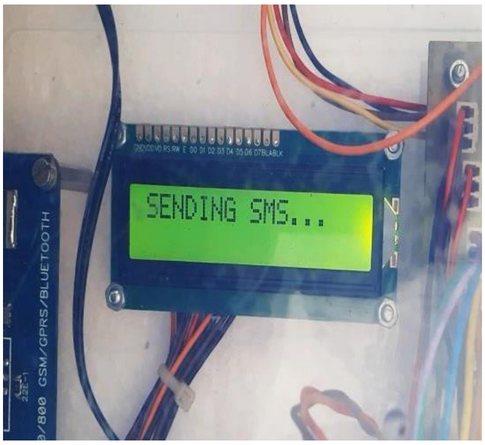


Plate 4.14 Sending SMS

Plate 4.15 Aerator working

The integration of real-time monitoring, alerting mechanisms, and corrective actions highlighted the efficiency and reliability of the system in managing critical water quality parameters for optimal aquaponics performance.

b) Monitoring and controlling of pH

The pH of the aquaponics system water was maintained within the optimal range of 6.5 to 7.5 to support healthy plant and fish growth. When the pH values deviated from this range, the system displayed an alert indicating. For instance, when the pH dropped to 4.8, as shown in Plate 4.16, the system issued an alert stating "pH is low" (Plate 4.17) and activated a beep sound. Simultaneously, an SMS notification was sent to the operator to prompt timely action (Plate 4.18).

In response to low pH levels, the system automatically triggered a solenoid valve connected to a pH buffer solution tank, adding the buffer to the fish tank to increase the pH. Conversely, when the pH exceeded 7.5, the system opened the solenoid valve linked to an external water tank containing slightly acidic water, which flowed into the fish tank to lower the pH (Plate 4.19).

Plate 4.16 Display showing pH 4.8

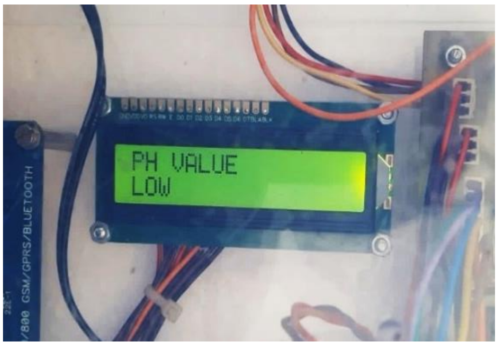


Plate 4.17 Alert showing pH low

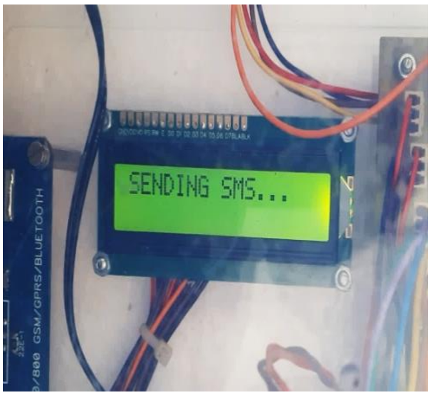


Plate 4.18 Sending SMS

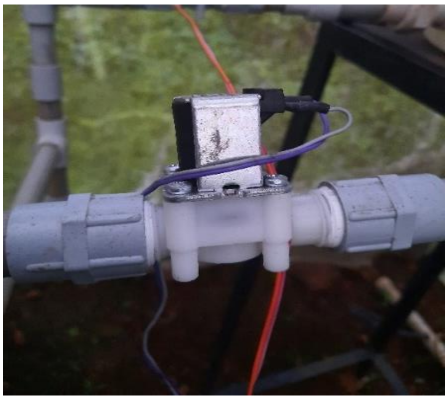


Plate 4.19 Working of solenoid valve

The automated pH management system effectively maintained water quality within the optimal range of 6.5 to 7.5, crucial for sustaining healthy plant and fish growth in aquaponics environments. The immediate activation of alarms, display alerts, and SMS notifications upon detecting deviations allowed for rapid corrective actions, minimizing stress on the biological components of the system. Automated dosing using solenoid valves for pH adjustment, either by adding a buffer solution or slightly acidic water, ensured consistent water chemistry without the need for manual intervention. This aligns with findings by Goddek *et al*. (2015), who emphasized the importance of real-time pH regulation for maintaining system stability and promoting nutrient availability in aquaponics systems.

A similar procedure was observed for other parameters; any deviation from the preset ranges resulted in an alert on the display, accompanied by a beep and an SMS notification, ensuring timely rectification of the issue.

c) Monitoring and controlling of water temperature and water level

The system utilized IoT-based temperature sensors to continuously monitor water temperature. Desired temperature range was maintained between 22°C and 32°C. However, on 12/08/2024, as shown in Fig. 4.12, the water temperature exceeded the upper threshold, reaching 33°C at 11:00 AM. The solenoid valve connected to an external water tank was activated, allowing cooler water to flow into the fish tank. This intervention effectively reduced the temperature to within the optimal range after a short period.

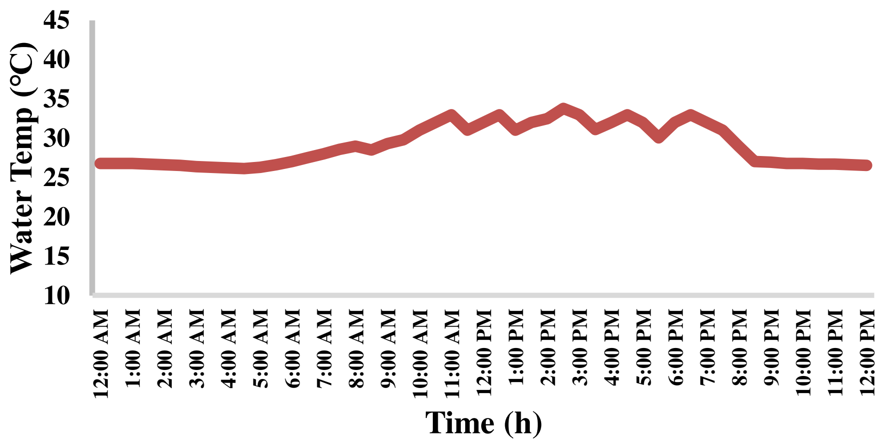


Fig 4.12 Daily variation of water temperature on 12/ 08/ 2024

The automated control of water temperature through IoT based monitoring enhanced the system's resilience against thermal stress, ensuring stable conditions critical for fish metabolism and plant nutrient absorption. The system's ability to autonomously detect deviations and trigger corrective actions minimized manual interventions, aligning with sustainable aquaponics practices. Maintaining stable water temperature is essential, as fluctuations can adversely affect fish metabolism and plant nutrient uptake, as noted by Yep and Zheng (2019). The automated response highlights the system's efficiency in maintaining water quality and temperature, critical for ensuring the health and growth of fish and plants in the aquaponics setup.

The system effectively monitored water levels using sensor to ensure optimal conditions for fish and plant health. On 12/08/2024, during the temperature correction process, the water level in the fish increased by adding of water and the level was monitored through the sensor, as shown in Fig. 4.13. This reduction in water level was detected by the sensor, which triggered an automated response.

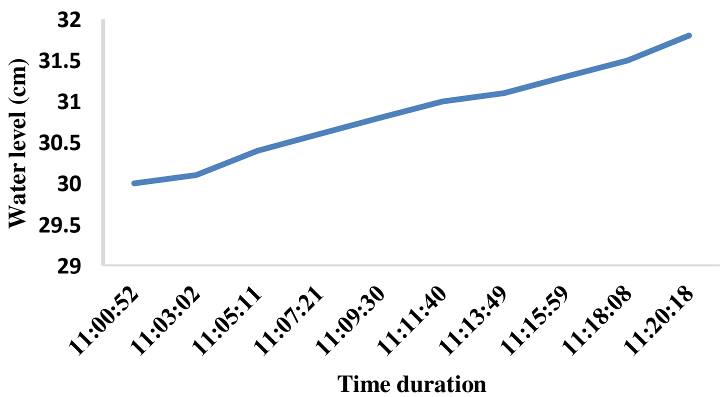


Fig 4.13 Variation of water level on 12/ 08/ 2024 at the time of water temperature correction

4.2.2 Weekly chemical analysis of ammonia and nitrate

Ammonia and nitrate levels in the fish tank were monitored weekly through chemical analysis suggested by Deswati *et al.* (2022) to ensure they remained within the recommended ranges for optimal system performance. Fig. 4.14 and Fig. 4.15 depict the weekly variations in ammonia and nitrate concentrations, while Fig. 4.16 illustrates the comparison between the amounts of ammonia and nitrate over the experimental period.

During the initial weeks, ammonia levels steadily decreased as the filtration system efficiently converted it into nitrate. This trend is evident in Fig. 4.14, where ammonia levels remained low, and Fig. 4.15 shows a corresponding increase in nitrate levels. By the final week of the experiment, on August 29, after three months of continuous operation, ammonia levels began to rise, as shown in Fig. 4.14. This increase correlated with the growth of the fish, leading to higher waste production. The filtration system showed signs of declining efficiency in converting ammonia into nitrate, as evidenced by a reduced nitrate concentration trend in Fig. 4.15. Ammonia levels ranged from 0.1 to 2.2 mg L^{-1}, primarily from fish excretion, while nitrate levels increased from 10 to 130 mg L^{-1}, as ammonia was converted into nitrate through the nitrification process facilitated by the filter. The comparison in Fig. 4.16 highlights this shift, where ammonia levels increased significantly compared to nitrate levels during the latter weeks.

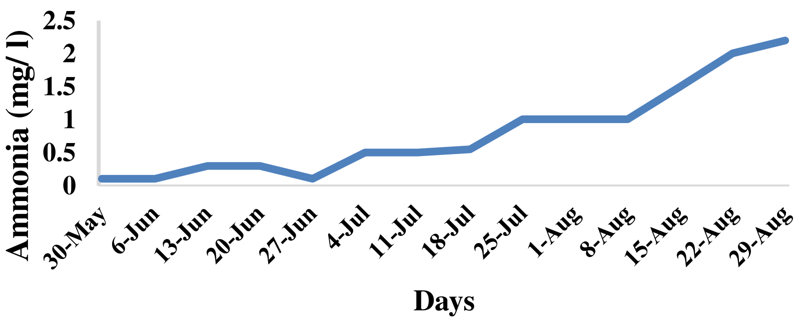


Fig. 4.14 Weekly variation of ammonia

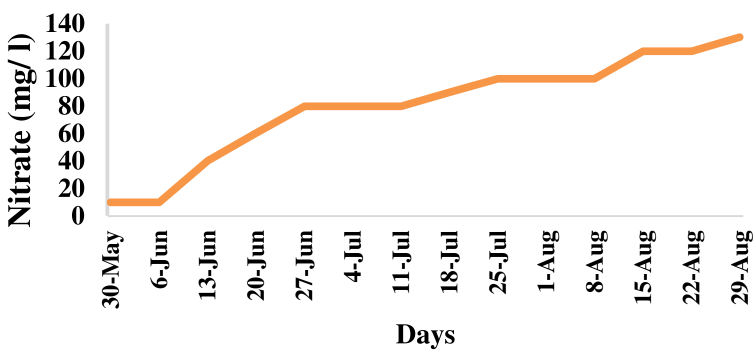


Fig. 4.15 Weekly variation of nitrate

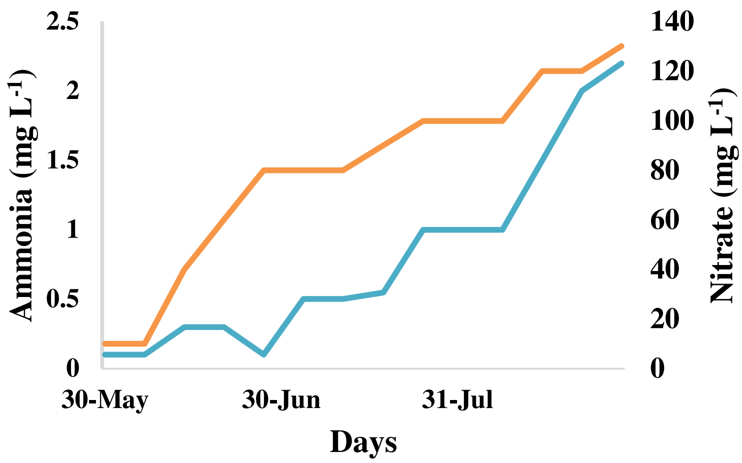


Fig. 4.16 Comparison of amount of ammonia and nitrate

These observations indicated the need for filter maintenance. Cleaning the filter was necessary to restore its efficiency and ensure the system's long-term stability. This result underscores the importance of regular filter maintenance in sustaining optimal aquaponics system performance.

4.2.3 Monitoring and controlling of water temperature, pH, dissolved oxygen, EC, air temperature, RH and water level over a day

Water temperature, pH, dissolved oxygen, EC, air temperature, RH and water level variation was observed on one day to check whether the IoT system have worked effectively by the proper working of solenoid valves and aerators. For this, parameters data were directly downloaded from the ThingSpeak in csv format. In ThingSpeak, data were uploaded every 2 minutes, resulting in more than 500 data points in a single day. Taking a large average of these values would not effectively capture fluctuations in the parameters. Therefore, values were considered at half-hour intervals to reflect parameter variations more accurately. The day 16/06/2024 was selected as it represented stable weather conditions, with an air temperature of 29°C and a relative humidity of 78%, making it suitable for assessing the system's performance under typical environmental conditions.

Water Temperature monitored on the date 16/06/24 (from 12.00AM to 12.00PM) is shown in Fig. 4.17 and it was found that the temperature has increased above 32°C at 12.30 PM and it was reduced to 31°C (approx.) after few minutes because of the automatic operation of solenoid valve and entry of water from water tank to fish tank.

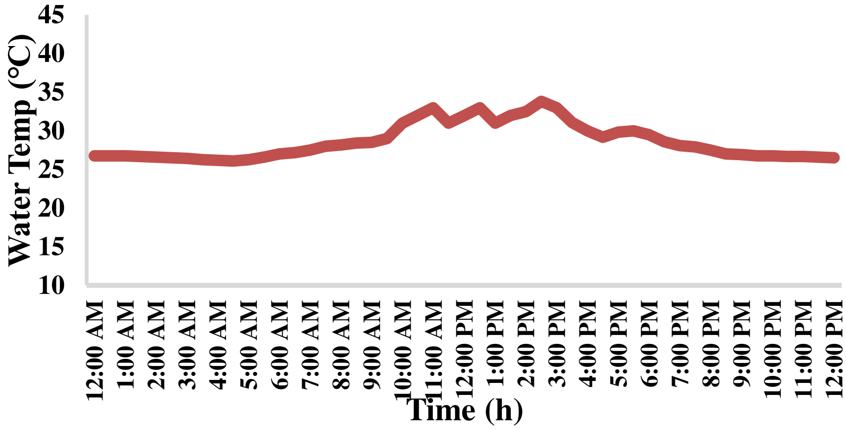


Fig. 4.17 Temperature monitored on 16/06/2024

Similarly, pH monitored on 16/06/24 (from 12.00AM to 12.00 PM) is shown in Fig. 4.18. It was found that pH was gradually increased above 7.5 at 5.30PM and reduced after some time due to flow of water from the water tank. The normal water was acidic in nature. In the morning, pH was lower and maintained by the solution from buffer solution tank.

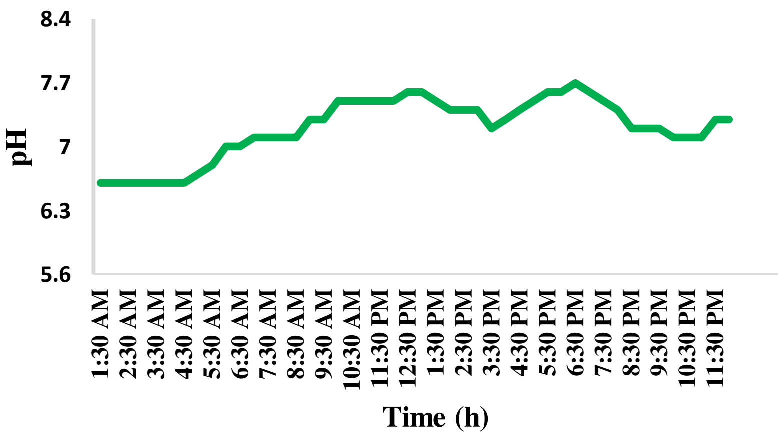


Fig. 4.18 pH monitored on 16/06/2024

On 16/06/24, DO levels were monitored from 12:00 AM to 12:00 PM, as shown in Fig. 4.19. The system effectively maintained DO levels above the threshold of 5.5 mg L^{-1}, with the aerator activating automatically when levels dropped. At 2:30 PM, DO briefly fell to 5.2 mg L^{-1}, likely due to increased biological oxygen demand, but the aerator promptly restored levels to the acceptable range. DO is essential for fish metabolism and overall system health, with levels below 5 mg L^{-1} known to cause stress in aquatic organisms (Timmons and Ebeling, 2013).

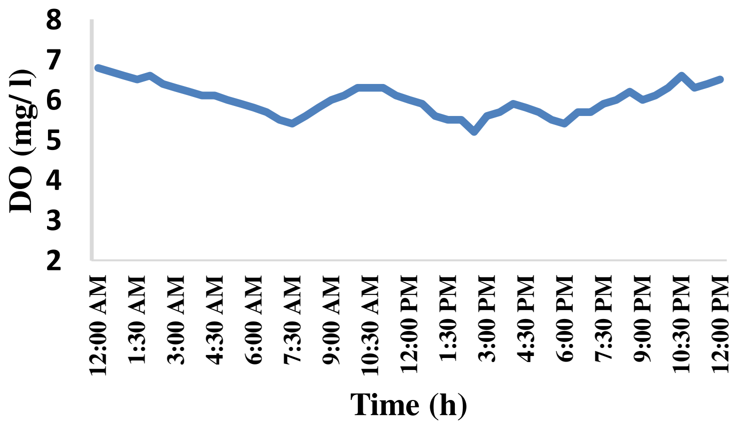


Fig. 4.19 DO monitored on 16/06/2024

Electrical conductivity (EC) monitored on 16/06/24 (from 12.00AM to 12.00 PM) is shown in Fig. 4.20. The EC in the aquaponics system was observed to vary continuously in response to changes in other parameters. Maintaining EC below 2 mS cm^{-1} was identified as optimal for system performance. The IoT-based system effectively managed EC by regulating other critical parameters, ensuring it remained within the desirable range. Significant deviations in EC were found to correlate with increased ammonia levels, which triggered automated alerts via SMS to prompt necessary precautionary measures.

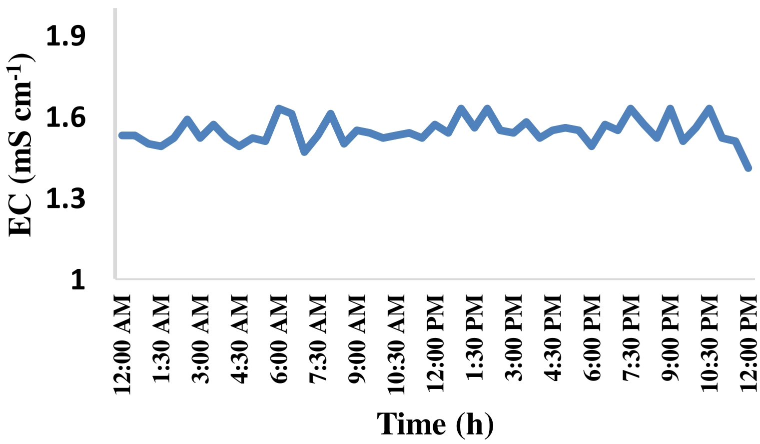


Fig. 4.20 EC monitored on 16/06/2024

The air temperature was monitored using the DHT22 sensor, and the data were uploaded to the ThingSpeak platform for real-time analysis. As shown in Fig. 4.21, the air temperature remained within the optimal range throughout the day, with slight variations observed at 11:00 AM and 2:00 PM. Despite these variations, the temperature remained favorable for the growth and performance of both fish and plants in the aquaponics system.

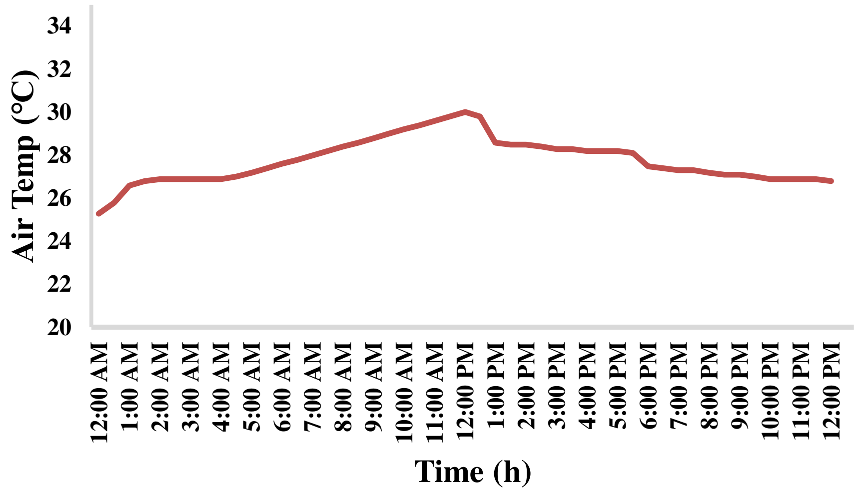


Fig. 4.21 Air temperature monitored on 16/06/2024

Similarly, relative humidity was continuously monitored and uploaded to the ThingSpeak platform for real-time observation. The data revealed daily variations in humidity levels, as shown in Fig. 4.22. These fluctuations were more pronounced during midday, coinciding with peak air temperatures between 11:00 AM and 2:00 PM. Despite these variations, relative humidity consistently remained within acceptable limits, providing an optimal environment for both plant and fish growth. The observed relative humidity levels reflect the dynamic interaction between temperature and ambient moisture content. The midday fluctuations align with increased evapotranspiration rates due to higher temperatures, a common phenomenon in controlled aquaponics environments (Somerville *et al.*, 2014). Maintaining relative humidity within an optimal range is crucial for plant photosynthesis and transpiration, as well as for fish health.

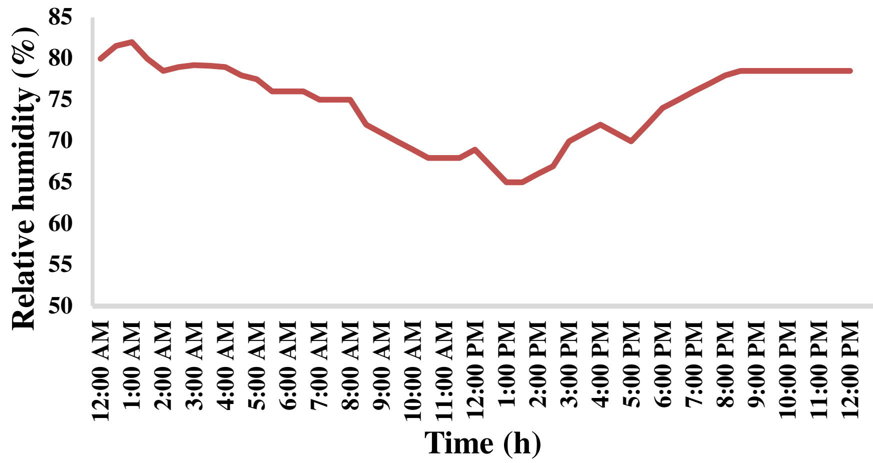


Fig. 4.22 Relative humidity monitored on 16/06/2024

The water level in the fish tank was continuously monitored to maintain optimal system operation, as shown in Fig. 4.23. During the monitoring period, the water level decreased to 36 cm (measured as the distance from the sensor), primarily due to air temperature effects and operational losses, such as evaporation. This drop in water level triggered the solenoid valve, allowing water from the external reservoir to replenish the fish tank. The system effectively restored the water level to its optimal range within approximately 30 minutes. This demonstrates the efficiency of the automated water level management system in maintaining stability in the aquaponics setup. Similar findings by Cruz Anchiraico *et al.* (2022) have highlighted the importance of automated systems in mitigating water losses and ensuring uninterrupted aquaponics operations.

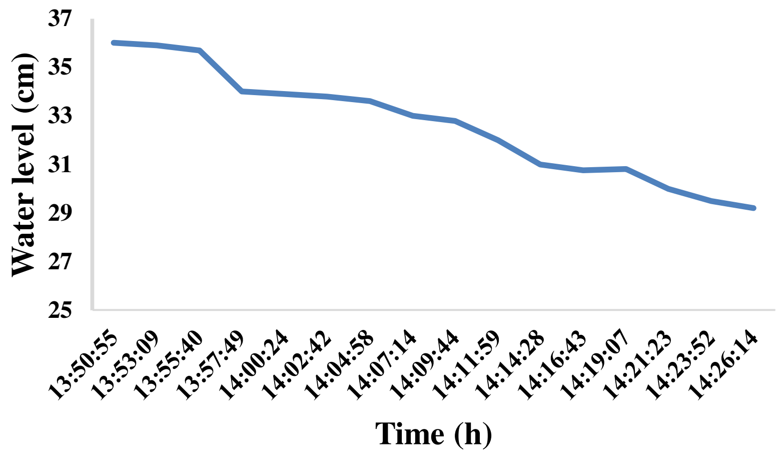


Fig. 4.23 Water level monitored on 16/06/2024

4.2.4 Monitoring and controlling of DO each month after transplanting

The Fig. 4.24 illustrates the variations in water temperature (°C) and dissolved oxygen (DO) levels (mg L^{-1}) over a 24 hour period (air temperature of 34°C), with aerator activation events indicated. The DO levels, shown by the blue line, were maintained around 6 mg L^{-1} for most of the day. However, significant drops in DO levels were observed at 7:00 AM, 2:00 PM, and 6:00 PM, reaching values close to 4 mg L^{-1}. These fluctuations can be attributed to variations in oxygen consumption rates within the system. Suhl *et al*. (2019) highlighted that oxygen consumption in recirculating NFT aquaponics systems is influenced by both plant and microbial activity. During early morning and late afternoon, lower photosynthetic rates, combined with increased microbial and fish oxygen demand, contribute to decreased DO levels. These reductions triggered the aerator, as indicated by the green spikes in the graph. The aerator activation restored DO levels to the optimal range (>5.5 mg L^{-1}), ensuring that the fish were not subjected to stress due to low oxygen concentrations. During the first month, the variation in DO levels was much lower, resulting in reduced operation of the aerator.

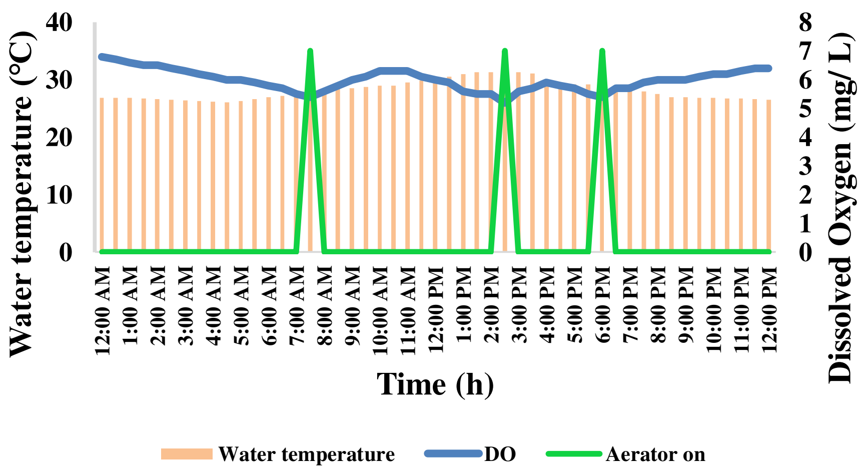


Fig. 4.24 DO and water temperature monitored on 08/06/2024

The graph (Fig. 4.25) shows the diurnal variation of water temperature and dissolved oxygen levels on 09/07/2024 (air temperature of 28°C). Water temperature gradually increased from 24.5°C at midnight to a peak of 28.8°C at 12:00 PM, before declining to around 25.5°C by evening. DO levels fluctuated between 4.5 mg L^{-1} and 5.8 mg L^{-1}, with significant drops observed at 1:00 AM, 6:00 AM, 12:00 PM, and 8:00 PM. These fluctuations can be attributed to the increased metabolic activity of fish during specific periods, leading to higher oxygen consumption. Homoki *et al.* (2021) reported that fish metabolic rates significantly impact DO levels in aquaponics systems, as oxygen demand rises during active periods. These reductions triggered the aerator, as indicated by the green spikes, effectively restoring DO levels to the optimal range. The system successfully maintained DO above the critical threshold of 4.5 mg L^{-1} within a favorable range, demonstrating the effectiveness of real-time monitoring and automated controls in ensuring optimal water quality.

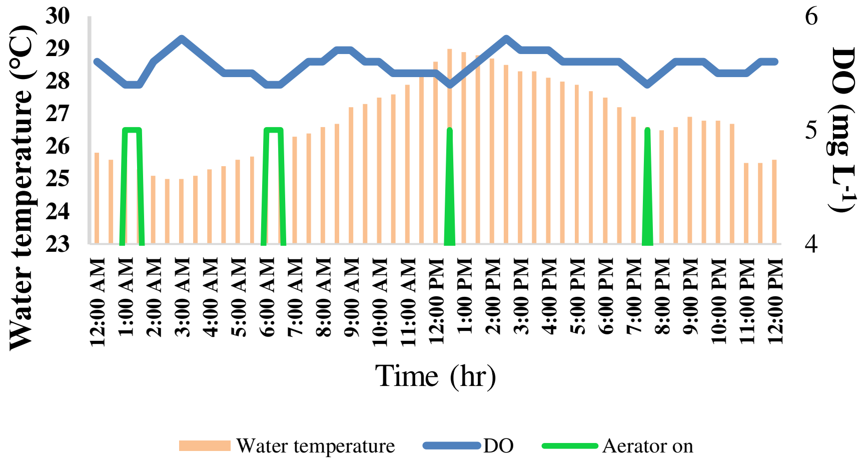


Fig. 4.25 DO and water temperature monitored on 09/07/2024

The graph (Fig. 4.26) illustrates the diurnal variation of water temperature and dissolved oxygen (DO) levels on 25/08/2024 (air temperature of 24°C). During the third month of the experiment, DO levels remained relatively stable between 5.0 mg L^{-1} and 5.6 mg L^{-1}, except for dips observed at 1:00 AM, 6:00 AM, 9:00 AM, 12:00 PM, and 6:00 PM, where DO dropped to 4.8 mg L^{-1}. These fluctuations can be attributed to the increasing growth of fish, as described by Khalil. (2018), where larger fish produce more waste and exhibit heightened metabolic activity, leading to greater oxygen consumption. Additionally, microbial activity in the system increases with higher organic waste levels, further contributing to oxygen depletion. These drops triggered the aerator, as indicated by green spikes, effectively restoring DO to optimal levels. The system successfully maintained water temperature and DO within favorable ranges, ensuring optimal conditions for fish and plant growth.

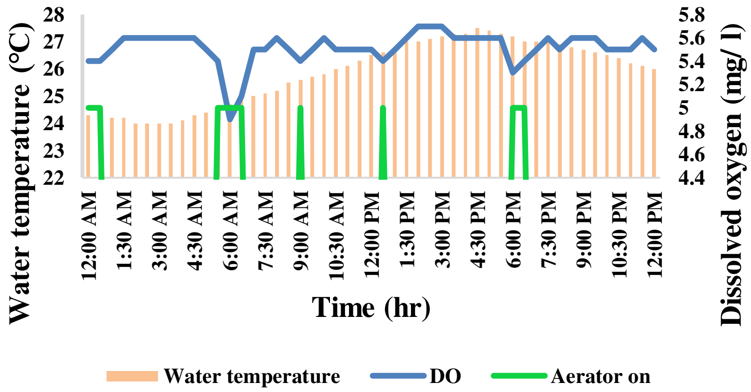


Fig. 4.26 DO and water temperature monitored on 25/08/2024

The DO and water temperature graphs monitored over three months of the aquaponics system indicate a progressive increase in the frequency of aerator operation. Initially, the aerator was triggered fewer times, as seen in the earlier months when fish metabolic activity was relatively low. However, as the experiment progressed, the frequency of aerator activation increased, particularly during early mornings and evenings, correlating with a decline in DO levels. This trend is attributed to the increased metabolic activity of the growing fish, leading to higher oxygen consumption and greater waste production. The system effectively maintained DO levels within the optimal range (4.8–5.6 mg L^{-1}) through timely aerator operation, ensuring a stable environment for fish and plant growth.

4.2.5 Monitoring and controlling of pH each month after transplanting

The Fig. 4.27 shows the variation in pH, DO, and solenoid valve activity monitored on 08/06/2024 over a 24-hour period. DO levels (blue line) generally decrease over time but showed sharp increases at 6:00 AM–8:00 AM and 5:00 PM–7:00 PM. The pH values (green bars) remained relatively stable throughout the day, fluctuating between 5.5 and 7.5, with a slight rise during the early morning hours, which coincided with the activation of solenoid valve and allow water from external water tank to the fish tank (red line). As discussed by Fatta-Kassinos *et al*. (2011), there is a close interdependence between pH and DO in aquaponics systems, primarily influenced by microbial activity and photosynthesis. Photosynthetic processes, which are more active during daylight, consume carbon dioxide and lead to an increase in pH, while simultaneously releasing oxygen, resulting in higher DO levels during these intervals. This relationship explains the observed morning and evening spikes in DO alongside the slight rise in pH.

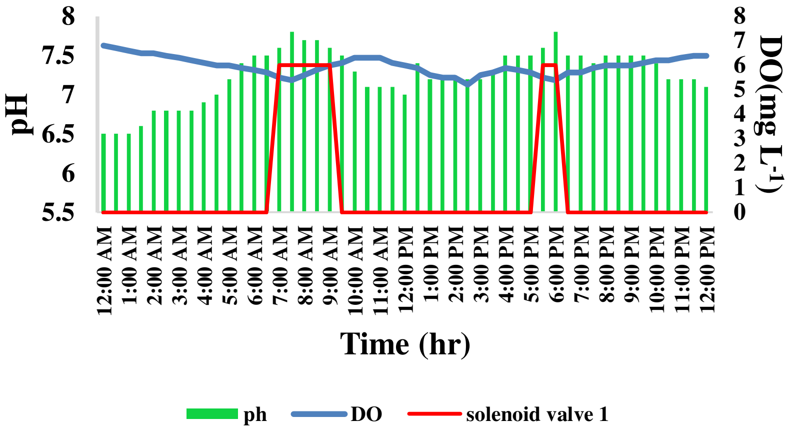


Fig. 4.27 pH and DO monitored on 08/06/2024

The pH and DO levels monitored on 09/07/2024 indicate that the pH remained relatively stable between 6.4 and 7.0 throughout the day, with minor fluctuations. A significant spike in solenoid valve activity (represented by the red line) was observed around 1:00 AM, indicating a decrease in pH levels. Overall, pH gradually increased during the day and peaked in the evening, showing better stabilization after early system adjustments as shown in Fig. 4.28.

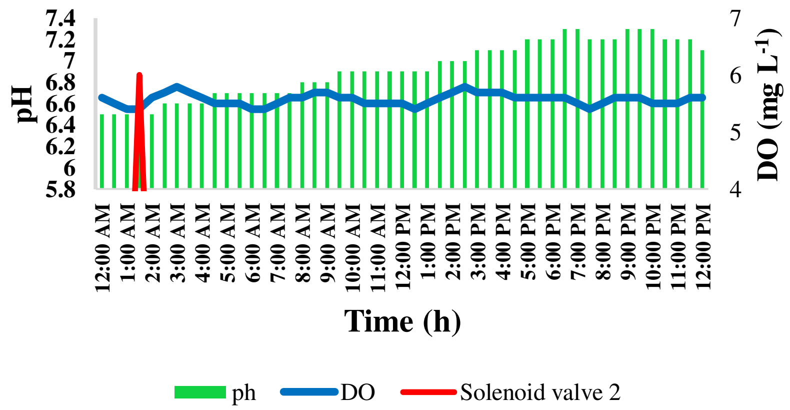


Fig. 4.28 pH and DO monitored on 09/07/2024

The Fig. 4.29 shows the variation in pH, DO, and solenoid valve activity monitored on 25/08/2024 over a 24-hour period. It was found that pH was high at 12:30 PM and 6 PM having value 7.6 and it controlled by adding water from external water tank to fish tank through solenoid valve.

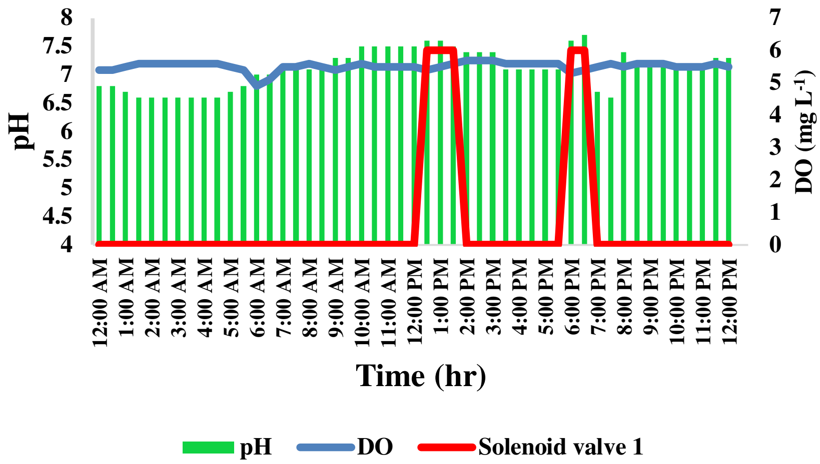


Fig. 4.29 pH and DO monitored on 25/08/2024

The system's ability to regulate pH and DO within acceptable range reflects effective water quality management, critical for sustaining optimal conditions in the aquaponics setup. The analysis of DO and pH levels in the aquaponics system revealed an inverse relationship between the two parameters. As DO levels increased, pH tended to decrease, and conversely, when DO levels dropped, pH showed a rising trend having resemblance with Ren *et al.* (2018).

4.2.6 Water quality analysis for aquaponics water from KWA

Water quality is critical for the efficient functioning of aquaponics systems, influencing both fish health and plant growth. Analysis of water samples from the fish tank and filtered water, conducted at the Kerala Water Authority, Manjeri, revealed notable differences.

Table 4.1 Parameters of fish tank water

Parameters	Values
pH	6.6
EC	1.2 dS m^{-1}
DO	5.8 mg L^{-1}
Ammonia	1 mg L^{-1}
Nitrate	40 mg L^{-1}

Table 4.2 Parameters of filtered water

Parameters	Values
pH	7.1
EC	1.5 dS/ m
DO	6 mg/ l
Ammonia	0.8 mg/ l
Nitrate	45 mg/ l

The fish tank water had a pH of 6.6, EC of 1.2 dS cm^{-1}, DO of 5.8 mg L^{-1}, ammonia at 1 mg L^{-1}, and nitrate at 40 mg L^{-1}shown in Table 4.1, indicating active nitrogen cycling but slightly elevated ammonia levels. After filtration, the water showed improved parameter values, a neutral pH of 7.1 increased EC of 1.5 dS/m, higher DO at 6 mg L^{-1}, reduced ammonia at 0.8 mg L^{-1}, and enhanced nitrate levels of 45 mg L^{-1}shown in Table 4.2. These changes reflected the filtration system's efficiency in stabilizing pH, improving aeration, reducing toxic ammonia, and converting it into nitrates for plant nutrition. The results align with recommendations by Timmons and Ebeling (2013), demonstrating the system's ability to maintain a balanced and sustainable environment for both fish and plants.

4.3 EVALUATION OF THE SYSTEM BASED ON GROWTH PARAMETERS

The developed IoT based automated aquaponics system for water quality monitoring and control was tested by growing palak plants and tilapia fishes. Palak harvesting was started 35 days after transplanting and continued regularly on alternate days.

4.3.1 Observations on growth parameters

Growth parameters such as plant height, number of leaves, leaf length, leaf width, and fish weight were monitored weekly to assess the performance of the aquaponics system. A total of 16 plants and 6 fishes were randomly selected for observation during each monitoring session as shown in Plate 4.20.

Plate 4.20 Monitoring plant height

4.3.1.1 Plant height

The plant height from 16 selected plants was measured (as a sum of shoot length and leaf length) weekly after transplanting. The average plant height is shown in Table 4.3 and its variation is shown in Fig. 4.30. It was found that plant height has increased substantially from May 30 to July 4.

Table 4.3 Average plant height measured weekly

Weeks	Plant height (cm)
Time of transplanting	9.3
1st week	11.07
2nd week	14.08
3rd week	15.96
4th week	19.34
5th week	21.69

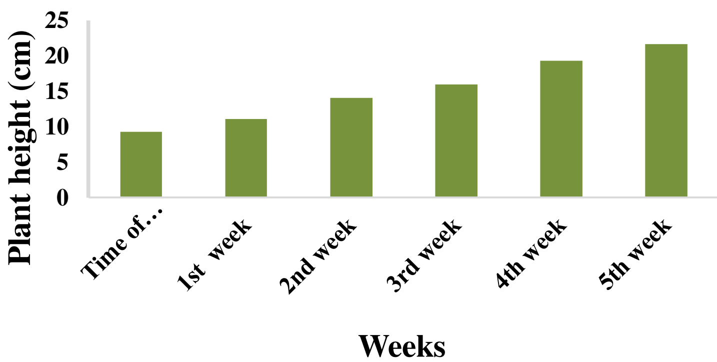


Fig. 4.30 Average plant height measured weekly

4.3.1.2 Number of leaves

Number of leaves from 16 selected plants was observed weekly. The average number of leaves is shown in Table 4.4 and its variation is shown in Fig. 4.31. It was found that number of leaves gradually increased from time of transplanting to week 6 and also showed good green colour at the end. Earlier it showed yellow colour on leaves due to nutrient deficiency.

Table 4.4 Average number of leaves per plant measured weekly

Weeks	Number of leaves
Time of transplanting	4
1st week	4
2nd week	5
3rd week	9
4th week	11
5th week	13

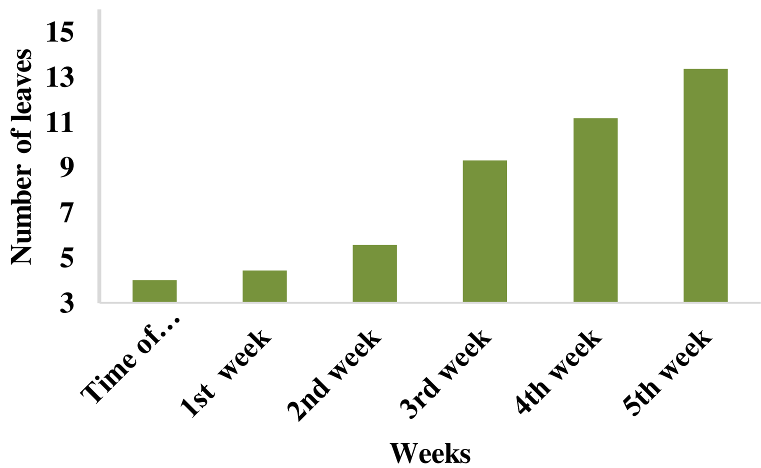


Fig. 4.31 Number of leaves *vs*. weeks

In the earlier stages of plant growth, the number of leaves was noticeably lower due to a pest infestation that resulted in leaf damage. This challenge was addressed by applying neem-based pesticide, a natural and environmentally friendly solution. Following the pesticide application, the pest problem was effectively controlled, allowing the plants to recover and produce a healthy number of leaves in subsequent weeks.

4.3.1.3 Leaf length (cm)

Leaf length from 16 selected plants was observed weekly. The average leaf length is shown in Table 4.5 and its variation is shown in Fig. 4.32. It was found that leaf length gradually increased from time of transplanting to week 5.

Table 4.5 Leaf length measured weekly

Weeks	leaf length (cm)
Time of transplanting	4.08
1st week	4.97
2nd week	6.37
3rd week	7.98
4th week	10.55
5th week	12.37

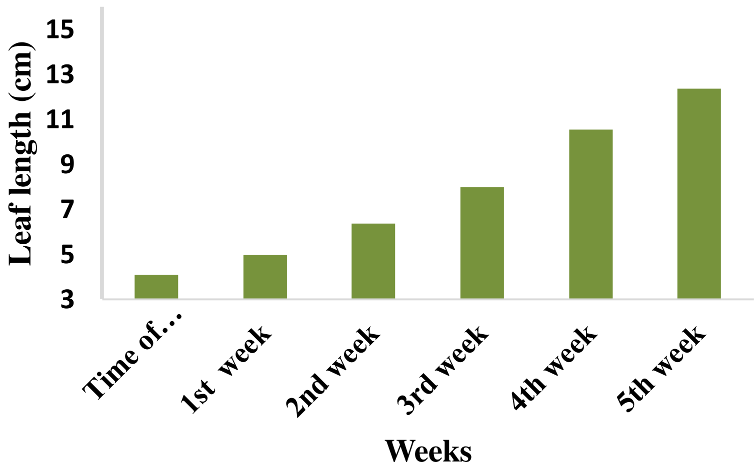


Fig. 4.32 Leaf length *vs* weeks

4.3.1.4 Leaf width (cm)

Leaf width from 16 selected plants was observed weekly. The average leaf width is shown in Table 4.6 and its variation is shown in Fig. 4.33. It was found that leaf girth gradually increased from time of transplanting to week 5.

Table 4.6 Leaf width measured weekly

Weeks	leaf width (cm)
Time of transplanting	3.1
1st week	3.99
2nd week	4.65
3rd week	7.33
4th week	8.46
5th week	10.66

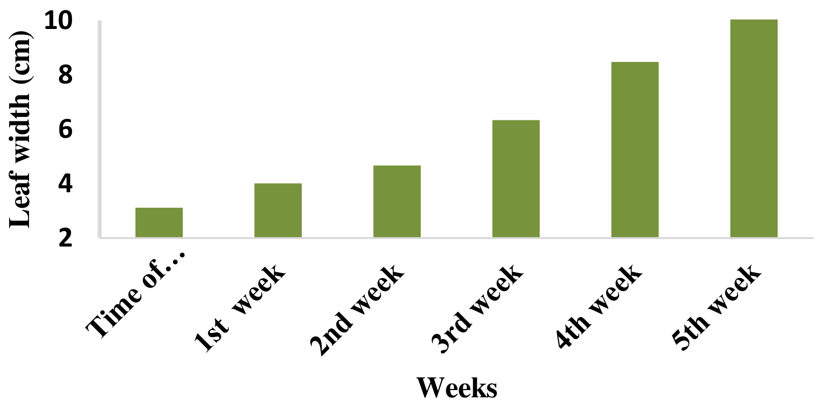


Fig. 4.33 Leaf width *vs* weeks

4.3.1.5 Fish growth rate analysis

The growth performance of Tilapia in the aquaponics system, as demonstrated by the specific growth rate (SGR), daily growth rate (DGR), and survival rate, indicates the system's effectiveness in maintaining optimal conditions for fish development.

Specific growth rate (SGR) was calculated using the following formula:

$$\text{SGR (\%/day)} = \frac{(ln(Final\,Weight) - ln(Initial\,Weight))}{Days\,of\,the\,Experiment} \times 100$$

$$= \frac{(\ln(5198) - \ln(1500))}{90} \times 100$$

$$= 1.38\%$$

$$\text{Daily growth rate (g/ day)} = \frac{final\,weight\,(g) - initial\,weight(g)}{culture\,period\,(d)}$$

$$= \frac{207.94 - 60}{90} = 1.64 \text{ g/ day}$$

$$\text{Survival (S)} = \frac{\text{final number of fish}}{\text{initial number of fish}} \times 10 \text{ (Tolussi } et\ al.\text{, 2010)}$$

$$= \frac{25}{25} \times 100$$

$$= 100\%$$

The calculated SGR of 1.38%/day is consistent with previous studies on tilapia in integrated aquaponics systems, which typically report growth rates ranging between 1% and 2%/day under ideal conditions (Yildiz *et al.*, 2017, Sirsat and Neal, 2013). This suggests that the nutrient cycling and environmental conditions in the system were well-regulated, supporting efficient fish metabolism and growth.

The DGR of 1.64 g/day reflects a steady increase in fish biomass over the 90 day culture period, demonstrating the adequacy of feeding practices and water quality management. The survival rate of 100% is a notable achievement, indicating that the system provided a stress-free and healthy environment, free from significant disease outbreaks or adverse conditions. High survival rates are critical for the economic viability of aquaponics systems and align with findings from studies reporting survival rates above 95% in well-maintained setups (Rakocy *et al.*, 2006).

4.3.1.6 Feed Intake and conversion efficiency

$$\text{Feed conversion ratio (FCR)} = \frac{total\ weight\ of\ feed\ given\ (g)}{total\ fish\ weight\ gain\ (g)}$$

$$= \frac{7070}{5198}$$

$$= 1.36$$

$$\text{Feed efficiency ratio (FER)} = \frac{total\ fish\ weight\ gain\ (g)}{total\ weight\ of\ feed\ given\ (g)}$$

$$= \frac{5198}{7070}$$

$$= 0.735$$

The FCR was calculated to be 1.36, while the FER was 0.735. These values indicate that 1.36 kg of feed was required to achieve 1 kg of fish weight gain, showcasing an efficient feed utilization system. Such results are within the acceptable range for tilapia aquaculture in integrated systems (Rakocy *et al.*, 2006).

The FCR of 1.36 reflects a highly efficient conversion of feed into fish biomass, aligning with the values reported for tilapia in well-managed aquaponics systems. A lower FCR value indicates effective nutrient absorption and minimal feed wastage, which can be attributed to optimal water quality and controlled feeding practices. Similarly, the FER of 0.735 demonstrates the system's ability to support consistent fish growth relative to feed input. These findings highlight the sustainability and cost-effectiveness of the aquaponics system for fish production, reinforcing its potential for resource-efficient aquaculture practices.

4.3.2 Observations on yield parameters

Yield parameters were monitored to evaluate the performance of the aquaponics system. Key metrics such as plant growth, plant yield, and fish yield were recorded throughout the study. Weekly observations were conducted to track the height, weight, and overall health of plants, as well as the growth and weight of fish. The results demonstrated a consistent increase in both plant yield and fish weight, indicating the system's efficiency in maintaining optimal conditions for growth.

4.3.2.1 Plant yield

The total plant yield observed in this study is showed in Table 4.7. The average yield per plant increased from 14.583 g on 4th July to a peak of 43.75 g on 3rd August, followed by a decline to 16.66 g by 17th August, resulting in a cumulative yield of 9.57 kg. The observed yield pattern, with an initial increase followed by a decline, is consistent with findings by Bittsanszky *et al.* (2016). Their study highlighted that plant growth in aquaponics systems peaks during optimal nutrient availability but may decline over time due to nutrient imbalances or waste accumulation, emphasizing the need for effective water quality management. These findings underscore the importance of continuous monitoring and management of nutrient levels and environmental conditions to sustain plant productivity in aquaponics systems.

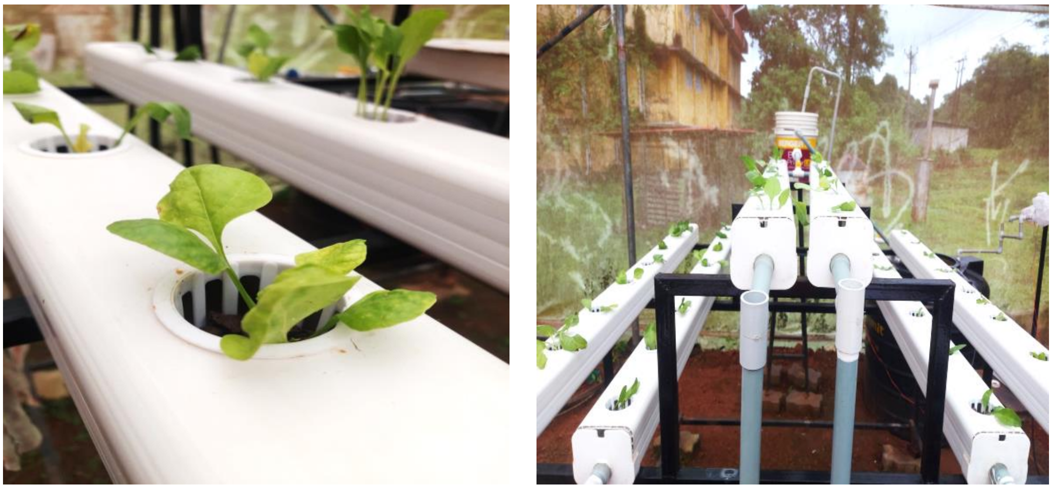


Plate 4.21 Plant growth at the time of transplanting

Plate 4.22 Plant growth after one week

Plate 4.23 Plant growth after two weeks

Plate 4.24 Plant growth after three weeks

Plate 4.25 Plant growth after four weeks

Plate 4.26 Plant growth after five weeks

Table 4.7 Total plant yield

Date of harvest	Average yield per plant (g)	Total yield (kg)
4-Jul	14.58	0.7
11-Jul	20.8	1.0
18-Jul	26.86	1.29
25-Jul	37.92	1.82
3-Aug	43.75	2.1
10-Aug	38.75	1.86
17-Aug	16.66	0.8
Total		9.57

Total yield = 9.57 kg

Required frame area for the grow bed,

Length of frame= length of channel= 1.5m

Width of frame= channel width+ spacing between channels

= 0.1+ 0.15= 0.25 m

Number of channels= 6

Frame area= 1.5×0.25×6= 2.25 m^2

Yield= 9.57 kg in 2.25 m^2 area

Yield per m^2= 4.25kg/ m^2

Total crop yield per hectare (t) = 4.25kg×10 = 42.5 t/ha

The yield performance of the developed IoT-based aquaponics system was compared with conventional hydroponics and traditional soil-based farming methods. In this study, the system achieved a palak yield of 4.25 kg/m². These results are higher than typical yields reported in conventional hydroponic systems, which generally range between 3.5 and 4.0 kg/m² for leafy greens such as spinach and lettuce (Resh, 2013). In contrast, soil-based farming methods yield approximately 2.5 to 3.0 kg/m² under average conditions (Ranawade *et al.*, 2017). The higher yield obtained from the aquaponics system can be attributed to optimized nutrient availability, real-time environmental monitoring, and automated control mechanisms that ensure ideal growing conditions.

4.3.2.2 Nutrient content analysis of plant leaves from RTL

The nutrient analysis of the plant leaves grown in the aquaponics system was conducted at the Radio Tracer Laboratory (RTL), where the dried leaf samples were submitted for testing. The results indicated essential macronutrients of 0.42% nitrogen, 0.15% phosphorus, and 0.24% potassium, suggesting effective nutrient uptake by the plants. The calcium and magnesium concentrations were 117.69 mg/kg and 20.15 mg/kg, respectively, supporting healthy plant growth. Micronutrient levels, including iron (15.80 mg/kg), manganese (3.01 mg/kg), and zinc (5.23 mg/kg), were found within typical ranges for plant development (Table 4.8).

Table 4.8 Nutrient content in plant leaf

Nutrient parameters	Values
Total nitrogen (%)	0.42
Total phosphorus (%)	0.15
Total potassium (%)	0.24
Total calcium (mg/ kg)	117.69
Total magnesium (mg/ kg)	20.15
Total iron (mg/ kg)	15.80
Total manganese (mg/ kg)	3.01
Total zinc (mg/kg)	5.23

The tested nutrient content values, including nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, and zinc, were sufficient for cultivating fruiting crops, which is consistent with findings by Roosta and Hamidpour (2013), who demonstrated the importance of balanced macro- and micronutrient levels for optimal plant growth in aquaponics systems.

4.3.2.3 Fish weight

Over the course of 14 weeks, the average weight of the fish showed a steady increase, highlighting the effectiveness of the system. Starting from an average weight of 60 g on May 30, the fish experienced consistent growth, reaching 97.4 grams by June 20 and 164.83 g by August 1. By the end of the growth period on August 29, the fish had an average weight of 207.94 g.

Plate 4.27 Fish weight after 11th week

Plate 4.28 Final weight of fish at the time of harvest

This steady increase in weight demonstrates the favorable conditions of the aquaponics setup, ensuring optimal fish yield and contributing to the overall sustainability of the system.

Table 4.9 Fish weight attained and quantity of feed consumed

Weeks	Average fish weight (g)	Total fish weight (g)	Quantity of feed given (g)
30-May	60	1500	
6-Jun	65.96	1649	245
13-Jun	76.23	1905.75	280
20-Jun	97.4	2435	315
27-Jun	113.13	2828.25	385
4-Jul	127.59	3189.75	420
11-Jul	139.32	3483	490
18-Jul	146.07	3651.75	525
25-Jul	155.83	3895.75	595
1-Aug	164.83	4120.75	665
8-Aug	175.23	4380.75	735
15-Aug	186.24	4656	770
22-Aug	194.74	4868.5	805
29-Aug	207.94	5198.5	840

Average fish weight (g) = 207.94 g

Total number of fish= 25

Therefore,

Total weight= 207.94× 25

= 5198.5 g= 5.198 kg

4.3.3 Comparative analysis of plant and fish growth rate

Fig. 4.34 illustrates the correlation between plant growth rate and fish growth rate over the duration of the study. The graph shows a positive linear relationship, indicating that as the fish grew, the plant growth rate also improved correspondingly. This trend supports the fundamental principle of aquaponics, wherein fish waste provides essential nutrients for plant development.

During the initial phase of the experiment, plant growth was relatively slower. This can be attributed to the insufficient accumulation of fish waste, as the fish biomass was still low and nutrient output was limited. As the fish gained weight and the microbial community in the biofilter matured, the availability of plant-usable nutrients- especially nitrogen compounds significantly increased. This is evident from the steeper slope in the latter part of the graph, indicating a more pronounced growth rate in plants, in sync with the increase in fish growth.

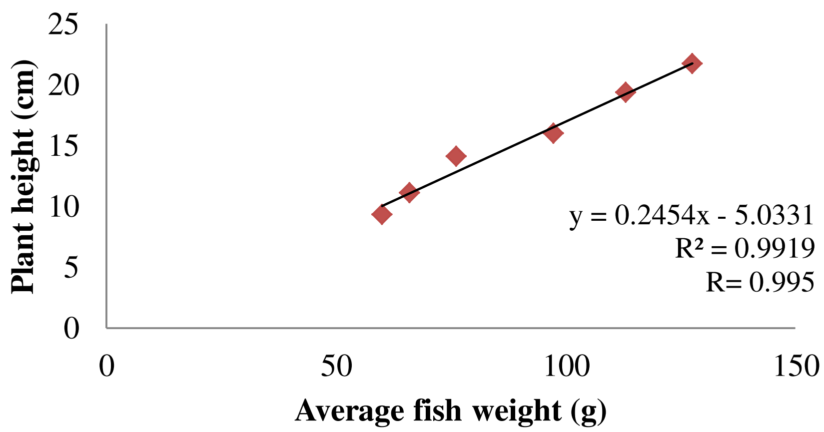


Fig. 4.34 Relationship between plant height and fish

This observation aligns with the findings of Palm *et al.* (2018), who emphasized that nutrient production in aquaponics systems is directly proportional to fish feed input and fish growth, with a lag in nutrient buildup at the early stages of system operation. Similarly, Graber and Junge (2009) highlighted that plant nutrient uptake improves significantly once microbial populations responsible for converting fish waste into plant-available forms are fully established. The strong correlation shown in the graph confirms the effective nutrient cycling within the system and supports its potential for balanced, integrated aquaponics production.

4.4 COST ANALYSIS OF THE DEVELOPED AQUAPONICS SYSTEM

The establishment of a functional aquaponics system requires a detailed cost analysis to assess its economic feasibility. The cost-benefit analysis of the aquaponics system yielded a benefit-cost ratio (BCR) of 2.67, demonstrating its strong economic feasibility. This aligns with the findings of Petrea *et al*. (2019), who reported that integrated aquaponics systems typically achieve high BCR values due to their dual production model, which optimizes resource utilization and minimizes waste. Such systems are highlighted as a sustainable and profitable approach to modern agriculture, capable of providing economic returns while maintaining ecological balance.

Table 4.10 Structural cost analysis

Sl. No.	Materials	Price (Rs)
1	GI pipe	3000
2	NFT channels (uPVC material)	1800
3	End caps	600
4	Net pots	250
5	Fish tank (500 L)	1500
6	Tanks (25 L)	600
7	20 mm PVC pipes	1500
8	Pump	1200
9	Pipe fittings	300
10	Aerator	280
	Total	11030

Table 4.11 Components cost analysis

Sl. No.	Materials	Price (Rs.)
1	pH sensor	1100.00
2	EC sensor	800.00
3	DO sensor	4060.00
4	Ultrasonic sensor	330.00
5	Water flow sensor	550.00
6	Water temperature sensor	600.00
7	DHT22 sensor	250.00
8	PIC microcontroller	600.00
9	Solenoid valve	900.00
10	Relay	1000.00
11	GSM module	650.00
12	Extension board	500.00
13	USB cable	90.00
14	Adaptor	200.00
15	Wire	150.00
16	LCD display	220.00
	Total	12000.00

$$Depreciation = \frac{\text{Capital cost} - \text{Salvage value}}{\text{Useful life}}$$

Salvage value = 10% of capital cost

Useful life of system = 8 years

$$Dep\quad eciation = \frac{\text{Structural cost} - \text{Salvage value}}{8}$$

$$Depreciation = \frac{11030 - 1103}{8 \times 365} = 3.39\ Rs\ per\ day$$

$$Depreciation = \frac{\text{Components cost} - \text{Salvage value}}{5}$$

$$Depreciation = \frac{12000 - 1200}{5 \times 365} = 5.9\ Rs\ per\ day$$

$$Total\ Depreciation = 3.39 + 5.9 = 9.29\ Rs\ per\ day$$

$$Interest = \frac{\text{Capital cost} + \text{Salvage value}}{2} \times \frac{\text{annual interest}}{365}$$

Annual interest = 12%

$$Interest = \frac{23030+2303}{2} \times \frac{0.12}{365} = 4.16\ Rs\ per\ day$$

$$Fixed\ cost = 9.29 + 4.16 = 13.45\ Rs\ per\ day$$

Table 4.12 Variable cost analysis

S. No.	Particulars	Value (Rs.)/day
1	Plant cost	1.50
2	Feed cost	3.00
3	Electricity cost	0.05
	Total	4.55

Total cost of production= Fixed cost + variable cost

Total cost of production= 13.45 + 4.55= 18 Rs per day

Total palak production for 80 days= 957 g

To calculate cost benefit ratio, production per day is considered = 11.96 g

Total fish production for 100 days = 5198 g

Production per day is considered= 51.9 g

Gross return= 46.71+ 1.46= 48.17 Rs

$$Benefit\ cost\ ratio = \frac{\text{Gross return}}{\text{Cost of production}} = \frac{48.17}{18} = 2.67$$

A detailed cost analysis was conducted to evaluate the structural and electronic components of the aquaponics system. The total structural cost, amounted to Rs. 11,030 (Table 4.10). Electronic components such as sensors (pH, EC, DO, temperature), a PIC microcontroller, GSM module, LCD, and automation hardware totaled Rs. 12,000 (Table 4.11). Depreciation was calculated using the straight-line method, assuming a salvage value of 10% and useful life of 8 years for structural components and 5 years for electronics. The daily depreciation cost was Rs.9.29, and interest on capital investment was Rs. 4.16 per day, resulting in a fixed cost of Rs. 13.45 per day. Variable costs added up to Rs. 4.55 per day (Table 4.12). The total production cost was Rs. 18 per day. With a daily yield of 11.96 g of palak and 51.9 g of fish, the gross return was Rs. 48.17 per day, leading to a benefit-cost ratio of 2.67, indicating economic viability and efficiency of the system.