Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 375 – 389 (2025)
www.ejabf.journals.ekb.eg

Correlation of Water Quality Parameters in a Recirculating Aquaculture System for the Nile Tilapia (*Oreochromis niloticus*) Cultivation

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ARTICLE INFO
Article History:
Received: Jan. 25, 2025
Accepted: July 2, 2025
Online: July 10, 2025

Keywords:
Correlation,
Tilapia,
Recirculating aquaculture system,
Water quality

ABSTRACT

The Nile tilapia (*Oreochromis niloticus*) is widely favored for its high nutritional value, which offers health benefits for human consumption. Aquaculture practices are commonly employed to meet growing consumer demand. One effective method is the Recirculating Aquaculture System (RAS), known for its efficient water use, waste management, and stable water quality. However, maintaining water quality remains a key challenge due to residual feed, fish waste, and environmental influences. This study examined the correlations among various water quality parameters within a RAS specifically used for the Nile tilapia cultivation. Maintaining optimal water conditions ensures fish health and maximizes production efficiency. The parameters assessed in this research include temperature, pH, dissolved oxygen (DO), and ammonia (NH_3). The RAS setup consisted of fiber filters, pumice, activated charcoal, and bioballs, operating with a single grow-out tank for the Nile tilapia. Over a 42-day monitoring period, data collection was weekly carried out. Based on results, a strong positive correlation between pH and ammonia was recorded in the culture pond (r= 0.72). Negative correlations were observed between temperature and ammonia (r = –0.31) and temperature and pH (r = –0.30). No significant correlation was found between DO and pH (r = 0.34). These findings indicate that while the RAS helps stabilize water quality, the interactions between parameters still influence system performance and fish health. Proper monitoring and management of these parameters are essential to support optimal Nile tilapia RAS farming production.

INTRODUCTION

The Nile tilapia (*Oreochromis niloticus*) is one of the most widely cultivated freshwater fish species, valued for its role as a source of affordable animal protein **(Munguti *et al.*, 2022)**. The Nile tilapia meat contains 22.167±0.44g of protein, 2.5 ± 0.28g of fat (primarily healthy unsaturated fats), omega-3 fatty acids, and a variety of essential vitamins, including A, B3, B6, C, and E, along with essential minerals such

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as selenium, calcium, potassium, iron, sodium, and iodine **(Afzal *et al.*, 2024)**. These nutritional advantages make the Nile tilapia highly favorable for human health and food security.

Cultivating the Nile tilapia offers economic and ecological benefits; however, water quality management remains a critical challenge in achieving optimal fish growth and survival. Tilapia are sensitive to extreme environmental changes, particularly temperature fluctuations. The optimal temperature range is between 25–30°C; deviations from this range can cause stress, reduced growth, or mortality **(El-Hack *et al.*, 2022)**. Likewise, although tilapia are more tolerant of low dissolved oxygen (DO) than other species, insufficient DO levels can compromise growth performance and disease resistance. Additionally, ammonia (NH_3), a toxic byproduct of fish metabolism and decomposing organic matter can accumulate and negatively affect fish health if not adequately managed **(Ngoepe *et al.*, 2021)**.

The Recirculating Aquaculture System (RAS) has emerged as a sustainable and efficient solution to address these challenges. RAS recycles water through mechanical and biological filters, reducing overall water use while maintaining stable water conditions. Biological filtration is key in converting toxic ammonia into less harmful compounds through nitrification. Compared to conventional systems, RAS minimizes environmental impact, enables higher stocking densities, and allows for precise control of water parameters **(Aich *et al.*, 2020)**.

While much research has focused on individual water quality parameters or the overall performance of filtration systems, fewer studies have examined how these parameters interact over time in the context of RAS-based Nile tilapia farming. In reality, water quality parameters are highly interconnected: temperature influences dissolved oxygen (DO) solubility; pH affects ammonia toxicity; and DO levels impact microbial activity and nitrification rates. For example, higher temperatures reduce DO levels and increase ammonia toxicity. Similarly, alkaline pH conditions raise the proportion of un-ionized ammonia (NH_3), which is highly toxic to fish **(Kumar *et al.*, 2023)**.

This study addressed this gap by analyzing the correlation between water quality parameters temperature, pH, DO, and ammonia in a RAS designed for the Nile tilapia cultivation. The novelty of this research lies in identifying how these parameters influence each other throughout the production cycle, providing insights for more precise and proactive water quality management in intensive aquaculture systems. Understanding these interactions is critical to improving fish health, minimizing stress, and increasing the sustainability and efficiency of RAS-based tilapia farming.

MATERIALS AND METHODS

1. Time and place of research

The research was conducted between January and March 2024 at the People's Fisheries Business (PFB) site in Progosari, Karang Harapan, Juata Kerikil Subdistrict, Tarakan City. Water quality parameters such as temperature, pH, and dissolved oxygen (DO) were measured on-site (*in situ*). At the same time, ammonia concentrations were analyzed off-site (*ex-situ*) at the Water Quality Laboratory of the Faculty of Fisheries and Marine Science, Universitas Borneo Tarakan. These measurements were weekly taken to monitor changes in water quality throughout the 42-day observation period.

2. Tools and materials

The equipment used in this study included a filtration system consisting of fiber, pumice stone, activated charcoal, and bioballs, along with nets, sample bottles, water pumps, thermometers, pH meters, DO meters, and a UV-Vis spectrophotometer. The materials used comprised the Nile tilapia (*Oreochromis niloticus*) fry, F999 commercial feed, distilled water (aquadest), phenol solution, nitroprusside reagent, and an oxidizing agent.

3. Research procedure

3.1. Construction and installation of the RAS culture tank system

The recirculating system utilized in this study consisted of a concrete tank measuring 2 × 3m with a height of 0.8m, connected to a single filtration unit. Before use, the tank was thoroughly cleaned and air-dried for 1–2 days. It was then filled with 3000L of spring water sourced from a nearby mountainous area, which was first allowed to settle to improve water quality. The culture tank was connected to a recirculation system via an outlet pipe leading to a filter chamber and an inlet pipe returning the treated water to the culture tank. The filtration unit comprised a 350L drum that was cleaned and dried before setup. Filter media were arranged vertically within the drum and wrapped in netting sequentially of coconut fiber (coir), pumice stones, activated charcoal, and bioballs. A water pump with a capacity of 5800 L/hour was used to ensure continuous and efficient water recirculation throughout the system **(Lembang *et al.*, 2023)**. The recirculating system setup is depicted in Fig. (1).

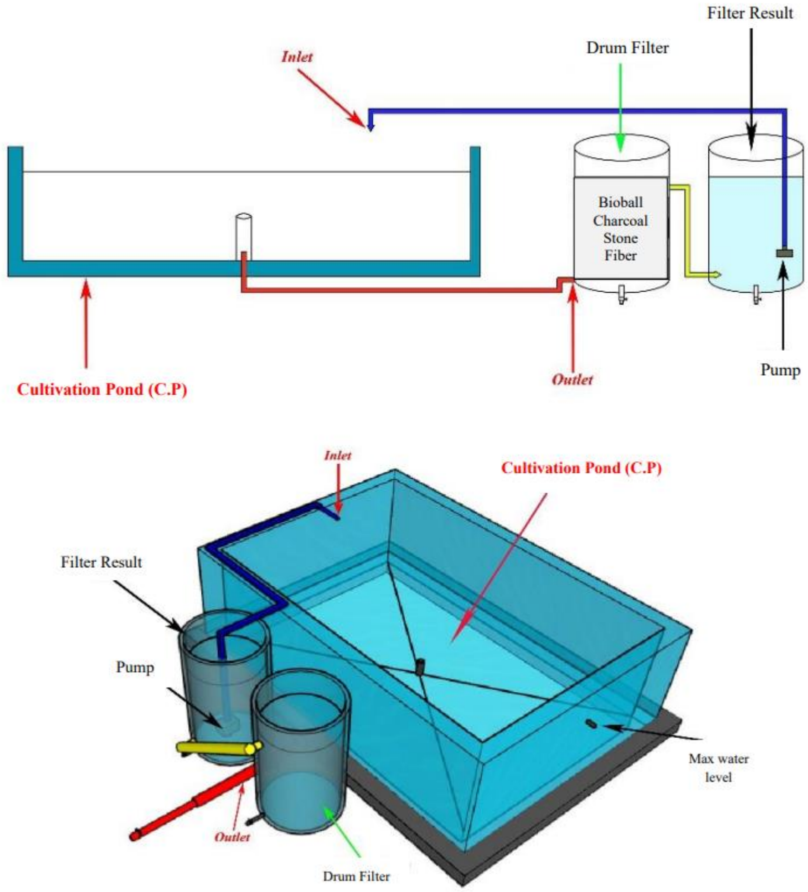

Fig. 1. Recirculating aquaculture system installation **(Lembang *et al.*, 2023)**

3.2. Culture maintenance and feeding procedures for the Nile tilapia

A total of 3000 Nile tilapia (Oreochromis niloticus) fry, with an average size of 6.14 ± 0.21cm and 3.56±0.41g, were stocked and reared in a maintenance container with a stocking density ratio of fish to water of 1:1 according to **Nugroho**'s **(2013)** modification. Before stocking, the fish were selected based on uniform size and health condition. Fish were fed with commercial pellets (F999) containing balanced nutrients appropriate for tilapia growth. Feeding was carried out twice daily, in the morning and afternoon, at a rate of 3% of the total biomass per day, with feeding frequency twice daily at 08.00 AM and 04.00 PM. Feed amounts were adjusted weekly based on biomass estimation. Water was not replaced during the study period, relying entirely on the RAS filtration and circulation to maintain water quality.

3.3 Observation and measurement of water quality

Water quality was monitored and measured both *in situ* and *ex situ* on a weekly basis over a 42-day period. Observations were conducted at three specific sampling points: the inlet, outlet, and culture pond (C.P.). *In situ* parameters such as temperature (thermometer), pH (pH meter), and dissolved oxygen (DO meters) were directly measured at the site, while ammonia levels were analyzed *ex situ* in the laboratory to ensure accurate and consistent readings using UV-Vis Spectrophotometer. This approach allowed for comprehensive evaluation of spatial and temporal changes in water quality throughout the Recirculating Aquaculture System (RAS).

4. Data analysis

The data collected on water quality parameters, including temperature, pH, dissolved oxygen (DO), and ammonia, were analyzed using descriptive quantitative methods. This analysis involved calculating statistical measures of the range for each parameter at three sampling points: inlet, outlet, and culture pond every 7 days until 42 days. This analysis aimed to describe trends and variations in water quality over the 42-day observation period. Graphs were generated using Microsoft Excel 2021 to visualize fluctuations and facilitate interpretation. In addition, correlation analysis was conducted to assess the relationships between parameters using Pearson's correlation coefficient (r), with interpretation criteria based on the strength of the correlation.

The correlation coefficient (r) ranges from –1 to +1, where a value of 0 indicates no relationship between the variables. Correlation strength is interpreted as follows: 0.00–0.199 signifies a very weak relationship; 0.20–0.399 represents a weak relationship; 0.40–0.599: a moderate relationship; 0.60–0.799 stands for a strong relationship, and 0.80–1.00 a powerful relationship. A correlation value of +1 or –1 indicates a perfect linear relationship. Positive (+) values denote a direct correlation, where an increase in the other accompanies an increase in one variable. Conversely, negative (–) values indicate an inverse correlation, where an increase in one variable results in a decrease in the other **(Papageorgiou, 2022)**.

RESULTS

1. Water quality

Water quality monitoring in the recirculating aquaculture system (RAS) was conducted to evaluate the system's performance in maintaining stable conditions for the Nile tilapia cultivation. Measurements were taken over 42 days without any water replacement, focusing on three key points within the system: the inlet, outlet, and culture pond (Fig. 2).

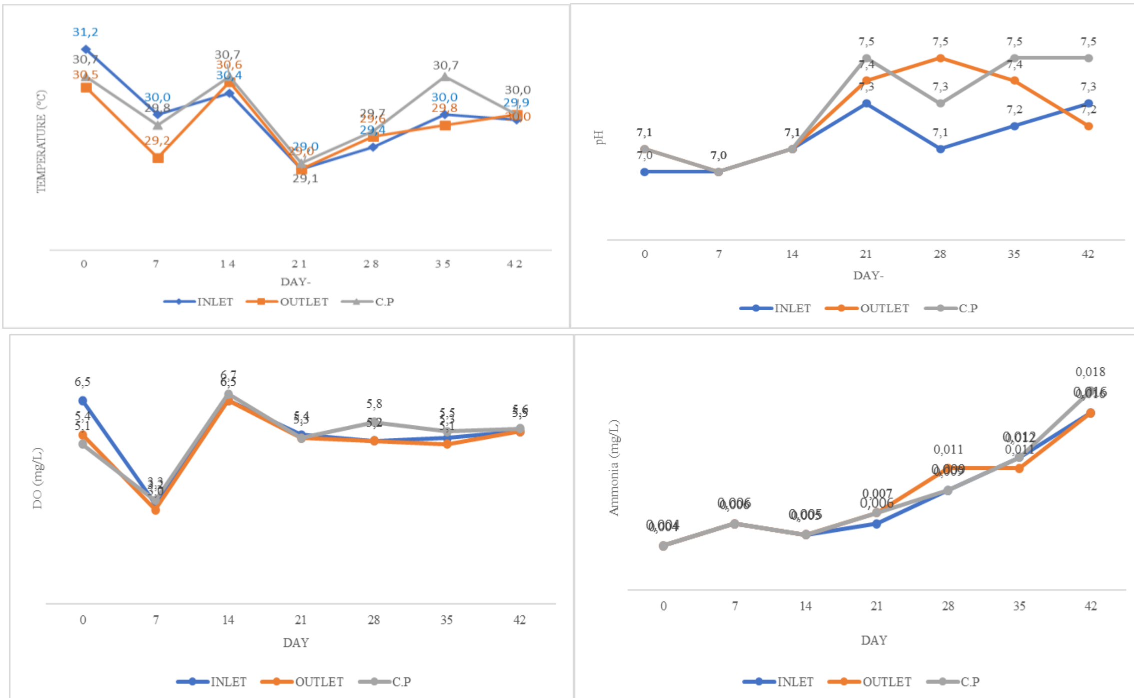

Fig. 2. Water quality parameters: **(a)** Temperature; **(b)** pH; **(c)** DO (Dissolved Oxygen); **(d)** Ammonia

- Temperature

Temperature was monitored over 42 days to observe fluctuations across different points in the recirculating aquaculture system (RAS). At the inlet, the lowest temperature was recorded on day 21 at 29.0°C, while the highest was on day 1, reaching 31.2°C. At the outlet, the temperature ranged from a low of 29.0°C on day 21 to a peak of 30.6°C on day 14. In the culture pond, the minimum observed temperature was 29.1°C on day 21, with a maximum of 30.7°C on days 0, 14, and 35. Overall, the recorded temperatures at all sampling points remained within the optimal range for the Nile tilapia cultivation, which is 25– 32°C.

- Acidity level (pH)

Acidity levels (pH) were monitored over 42 days at three points in the recirculating aquaculture system: the inlet, outlet, and culture pond. The results indicated that pH levels at all sampling points consistently remained within the acceptable range for the Nile tilapia cultivation. At the inlet, the lowest pH value of 7.0 was recorded on days 1 and 7, while the highest pH of 7.3 occurred on days 21 and 42. At the outlet, the pH also reached a low of 7.0 on day 7 and a high of 7.5 on day 28. In the culture pond, the lowest pH value of 7.0 was observed on day 7, with the highest value of 7.5 recorded on days 21, 35, and 42.

- Dissolved oxygen (DO)

Dissolved oxygen (DO) levels were monitored over 42 days at the recirculating aquaculture system's inlet, outlet, and culture pond. The results showed that DO levels at all three sampling points remained within the optimal range for the Nile tilapia fry, above 3.0 mg/L. At the inlet, the lowest DO concentration of 3.2 mg/L was recorded on days 1 and 7, while the highest level of 6.5 mg/L occurred on day 14. At the outlet, the minimum DO was 3.0 mg/L on day 7, and the maximum was 6.5 mg/L on day 14. In the culture pond, DO levels ranged from a low of 3.3 mg/L on day 7 to a peak of 6.7 mg/L on day 14. These results indicate that the system maintained adequate oxygenation throughout the study period to support the healthy growth of the Nile tilapia fry.

- Ammonia

Ammonia concentrations were measured over 42 days at the recirculating aquaculture system's inlet, outlet, and culture pond. The results showed a gradual increase in ammonia levels across all sampling points. At the inlet, the lowest ammonia concentration was recorded on day 1 at 0.004mg/ L, while the highest was 0.016mg/ L on day 42. Similarly, at the outlet, ammonia levels ranged from 0.004mg/ L on day 1 to 0.016mg/ L on day 42. In the culture pond, ammonia levels also increased, with the lowest value of 0.004mg/ L on day 1 and the highest value of 0.018mg/ L observed on day 42. Despite this increase, the recorded ammonia concentrations remained relatively low, indicating that the RAS effectively regulated nitrogenous waste throughout the study period.

2. Correlation between water quality parameters

Correlation analysis between water quality parameters was carried out to identify interdependent relationships and distinguish parameters that influence one another from those that do not. Understanding these relationships is essential for improving the management and control of water quality fluctuations that may negatively impact cultured organisms. Since each parameter varies in its level of toxicity and impact on fish health, recognizing which variables are correlated allows for more targeted interventions. This approach helps prevent adverse effects by addressing the root causes of water quality changes before directly affecting the aquaculture environment **(Kothari *et al.*, 2021)**.

- Temperature, pH, and DO (Dissolved oxygen) on ammonia

Correlation analysis revealed varying relationships between water quality parameters across the sampling points. A strong positive correlation was observed between pH and ammonia at the inlet (r = 0.6369) and culture pond (r = 0.7261), while a moderate correlation was found at the outlet (r = 0.4566). These positive values indicate a direct relationship, where an increase in pH is associated with an increase in ammonia concentration and vice versa **(Subandriyo, 2020)**. In contrast, the correlation between dissolved oxygen (DO) and ammonia showed a weak inverse relationship at the inlet (r = –0.1056), suggesting that higher DO levels may slightly reduce ammonia levels. However, the outlet (r = 0.0714) and culture pond (r = 0.1573) showed negligible correlations, indicating no significant interaction between DO and ammonia at those points. The analysis between temperature and ammonia indicated weak negative correlations at all locations: inlet (r = –0.2927), outlet (r = –0.1450), and culture pond (r = –0.0873). This suggests a general tendency for ammonia levels to increase as temperature decreases, although the relationships were not strong. These findings highlight the importance of monitoring multiple parameters simultaneously, as changes in one can influence others in ways that impact overall water quality and fish health.

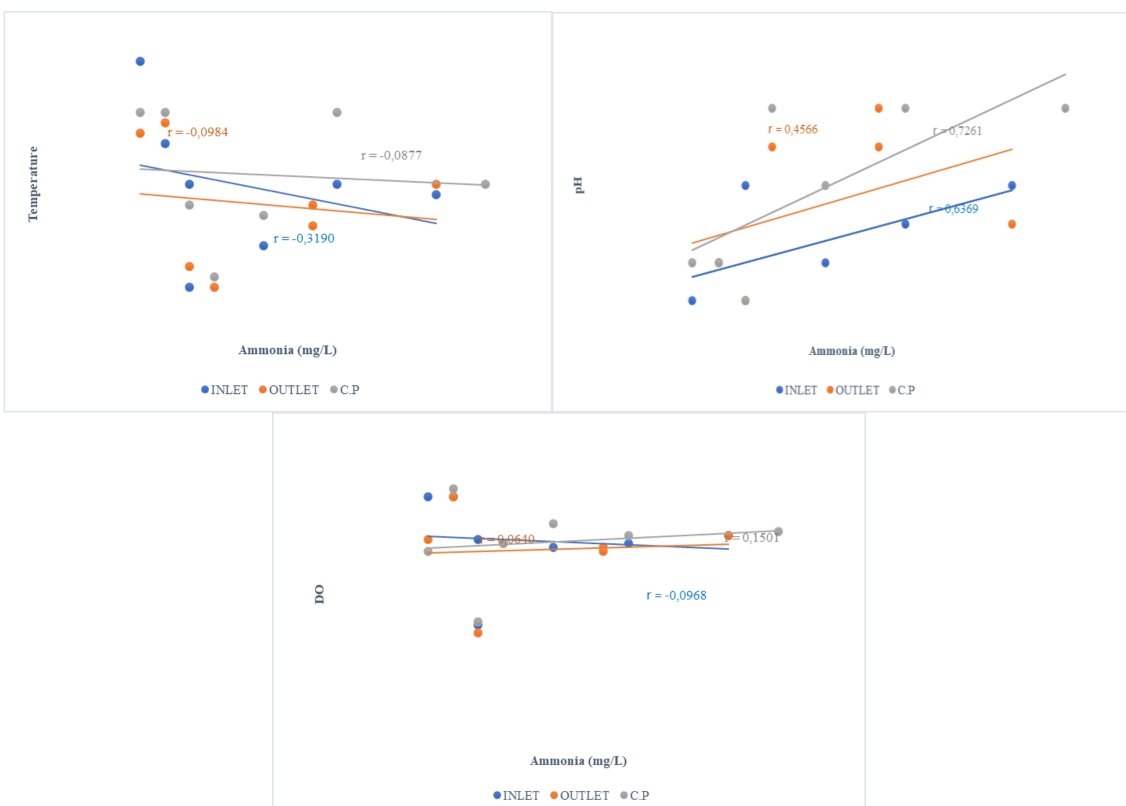

Fig. 3. Correlation, **(a)** Temperature and ammonia; **(b)** pH and ammonia; **(c)** DO and ammonia

- DO (Dissolved oxygen), temperature, and pH

The correlation between dissolved oxygen (DO) and pH showed very weak positive relationships in all sampling locations, with correlation coefficients of r= 0.1525 at the inlet, r= 0.2555 at the outlet, and r= 0.3413 at the culture pond. These low values indicate no significant relationship between DO and pH in the system. In contrast, an inverse correlation was observed between temperature and pH, with the strongest negative correlation at the inlet (r = –0.6252), followed by the outlet (r = –0.3672) and the culture pond (r = –0.3042). These negative values suggest that pH decreases as temperature increases and vice versa.

Meanwhile, the correlation between temperature and DO revealed positive relationships, with coefficients of r= 0.4007 at the inlet, r= 0.6483 at the outlet, and r= 0.3133 at the culture pond. These values indicate that an increase in temperature is generally associated with an increase in DO levels, although the strength of the relationship varies across sampling points. These findings highlight key interactions among water quality parameters in a recirculating aquaculture system, which can inform more effective management strategies to support fish health and system stability **(Lembang & Widiawati, 2022)**.

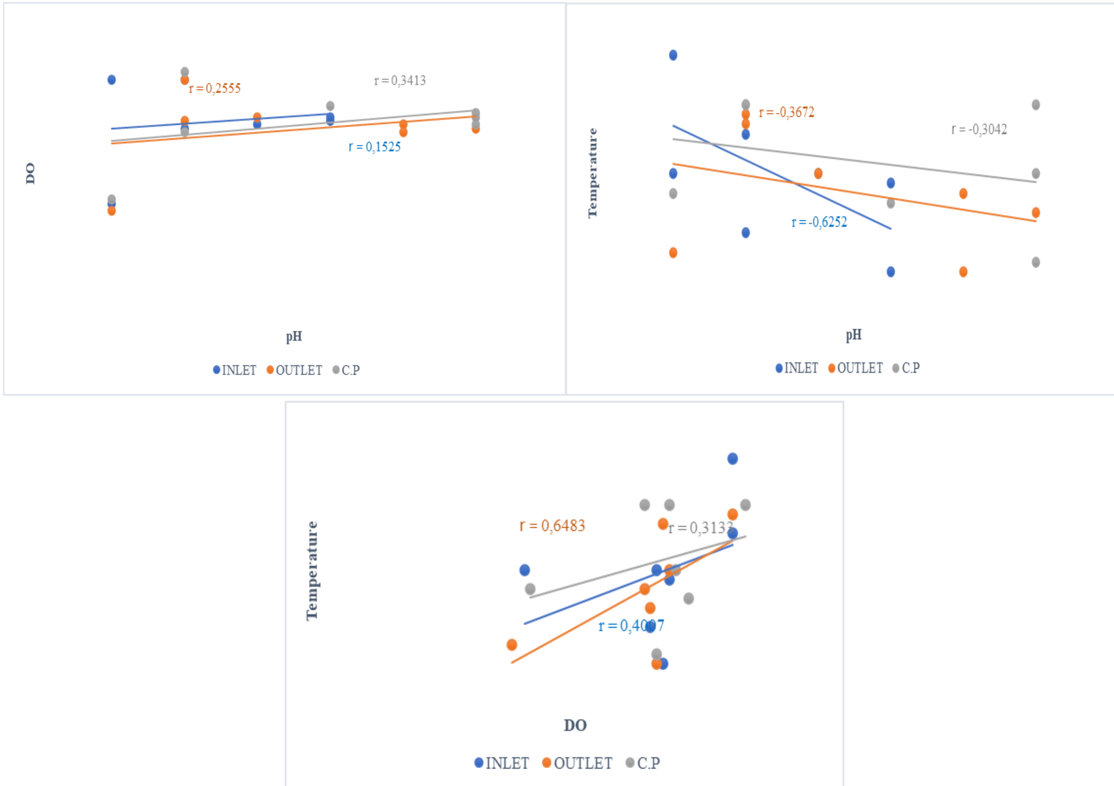

Fig. 4. Correlation, **(a)** DO and pH; **(b)** Temperature and pH; **(c)** Temperature and DO

DISCUSSION

Fig. (2) illustrates the temperature dynamics at the inlet, outlet, and fish-rearing pond over a 42-day observation period. The temperature across all sampling points remained relatively consistent, with the most stable values recorded at the inlet, followed by the outlet. This pattern indicates the effective role of the recirculating aquaculture system (RAS) in moderating thermal fluctuations. A slight temperature rise was noted on day 35 in the culture pond, potentially influenced by external environmental factors such as increased solar radiation or decreased cloud cover **(Hu *et al.*, 2018)**. Despite this, the overall fluctuations were minimal, showing no sharp increases or declines throughout the study. The temperature stability is primarily attributed to the mixing effect of the recirculating system, which distributes water evenly, minimizing thermal stratification between the surface and bottom layers **(Zhang *et al.*, 2024)**.

Temperature is a critical environmental parameter in aquaculture, as it significantly impacts the physiological functions of fish, including metabolism, respiration, feed intake, growth rates, reproductive performance, and immune responses **(Thesiana & Pamungkas, 2015; Lindholm-Lehto *et al.*, 2020)**. Exposure to temperatures beyond the optimal range can lead to thermal stress, suppressing immune function and increasing the risk of disease outbreaks. Environmental factors such as rainfall and ambient temperature directly influence water temperature; rain events typically reduce water temperature, while sunny and dry conditions may elevate it **(Lembang & Kuing, 2022)**.

In addition to temperature, pH levels were monitored, as shown in Fig. (2). The pH values throughout the 42 days remained within the optimal range for the Nile tilapia culture (6.5–8.5). The inlet showed the most stable pH trend, likely due to the proximity to the filtration unit, which plays a crucial role in buffering water quality changes **(Araújo *et al.*, 2017; Aich *et al.*, 2020)**. A noticeable increase in pH occurred on day 21, which may be attributed to the saturation or decreased efficiency of the biological filtration media **(Ncube *et al.*, 2018)**. In contrast, the pH at the culture pond was relatively stable but slightly higher than that of the inlet, possibly due to photosynthetic activity or reduced buffering capacity as water circulated. The outlet point displayed the most variability, which could be linked to the accumulation of metabolic waste, uneaten feed, and carbon dioxide from fish respiration **(Lembang & Widiawati, 2022)**.

Using coral stones in the filter media supports the recirculating system's ability to regulate pH. Coral, rich in calcium carbonate ($CaCO_3$), acts as a natural buffer by neutralizing excess acidity in the water. When pH drops, and the water becomes more acidic, $CaCO_3$ dissolves, releasing carbonate ions (CO_3^{2-}) that bind with hydrogen ions (H^+), reducing acidity and increasing pH. This buffering mechanism ensures a more stable environment for aquatic organisms **(Koenig & Liu, 2002; Boyd & Tucker, 2014)**.

Dissolved oxygen (DO) levels at the inlet, outlet, and fish-rearing pond remained relatively stable throughout the 42-day observation period, particularly on days 1, 14, and 42 (Fig. 2). This stability can be attributed to continuous water circulation within the Recirculating Aquaculture System (RAS), which facilitates aeration and oxygen distribution **(Lembang *et al.*, 2023)**. However, a notable drop in DO was observed on day 7, likely influenced by other water quality parameters, particularly ammonia. **Zhang *et al.* (2024)** reported that increased ammonia concentrations can reduce DO levels due to higher biological oxygen demand. The RAS technology maintains DO levels through its filtration system, which removes organic waste such as uneaten feed and fish excreta. These organic materials are broken down by aerobic bacteria, which consume oxygen and can reduce DO availability **(Preena *et al.*, 2021)**. Efficient recirculation also ensures uniform oxygen distribution throughout the system. Adequate DO is essential for the Nile tilapia, supporting respiration and other metabolic processes. Insufficient oxygen may cause physiological stress, impaired brain function, and, in extreme cases, fish mortality **(Siegers *et al.*, 2019)**.

Ammonia levels across the inlet, outlet, and culture pond remained within acceptable limits and showed a relatively stable pattern during the initial stages of the study (Fig. 2). However, from day 28 to day 42, a gradual increase in ammonia was observed at all sampling points. This trend may be linked to filter saturation due to prolonged usage, which reduces the filter's capacity to remove nitrogenous waste effectively. **Haynes (2015)** explained that filters have a finite absorption capacity, and over time, their performance diminishes as they reach saturation. Despite this, ammonia levels remained below the threshold for toxicity in tilapia farming (≤ 0.02mg/ L), suggesting that the system still maintained functional waste management. The primary sources of ammonia were likely fish feces and uneaten feed accumulating over time **(Norjanna *et al.*, 2015)**.

Fig. (3) presents the correlation between water quality parameters, highlighting their interdependence in the RAS. A significant relationship was found between pH and ammonia. At pH levels below 7, ammonia primarily exists as ammonium ions (NH_4^+), which are less toxic to fish. However, at pH levels above 7, a greater proportion of ammonia remains in its un-ionized form (NH_3), which is more toxic. The toxicity of un-ionized ammonia increases with both pH and temperature, emphasizing the importance of maintaining pH within the optimal range **(Shiwanand & Tripathi, 2013; Jin *et al.*, 2025)**.

DO plays a crucial role in aquaculture for fish respiration and supporting nitrification, a process where bacteria oxidize ammonia into less harmful compounds. This bacterial oxidation requires oxygen; thus, high ammonia concentrations can deplete DO **(John *et al.*, 2020)**. If DO falls too low, the physiological and metabolic processes of fish are negatively affected, leading to reduced growth and increased vulnerability to disease **(Wang *et al.*, 2023)**.

As shown in Fig. (4), the correlation between pH and DO was minimal, indicating that these parameters do not directly influence one another. This can be explained by the RAS design, which stabilizes both pH and DO independently through controlled water flow and effective filtration **(Xiao *et al.*, 2019)**.

Temperature and pH, however, showed a stronger inverse correlation. As temperature rises, chemical reactions such as acid dissociation increase, releasing more hydrogen ions (H^+) and a subsequent drop in pH **(Cui *et al.*, 2024)**. Temperature also significantly affects both DO levels and fish metabolism. Higher water temperatures reduce oxygen solubility while increasing fish metabolic rates and oxygen consumption. In contrast, low temperatures may suppress metabolism, reducing appetite and growth efficiency **(Jiang *et al.*, 2021)**.

CONCLUSION

The inlet and maintenance pond in the RAS tilapia system showed stable water quality over 42 days, while the outlet exhibited greater fluctuations. Water quality parameters were interrelated, with positive and strong correlations observed between pH and ammonia in the culture pond. Negative correlations occurred between temperature and ammonia, dissolved oxygen and ammonia (inlet), and temperature and pH. No correlation was found between dissolved oxygen and pH. These results underscore the need for targeted water quality monitoring in different zones of the RAS.

ACKNOWLEDGMENTS

This research was funded by Universitas Borneo Tarakan under research contract number 413/UN51.2/KPT/2024. The authors express their sincere gratitude for the support provided during the study.

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