

# Regression and Mixed-Effects Modeling of Fish Growth, Survival, and Yield in Semi-Intensive Aquaculture Systems in Gusau, Zamfara State, Nigeria

<sup>1</sup>Balkisu Hassan Augie, <sup>2</sup>Mubarak Hassan Augie, <sup>3</sup>Mansur Rabi

<sup>1</sup>Department of Biology, Federal College of Education (Technical) Gusau

<sup>2</sup>Department of Mathematics, Federal College of Education (Technical) Gusau

<sup>3</sup>Department of Statistics, Zamfara State University Talata-Mafara

Corresponding Author's Email: [Mubarakhassan7@gmail.com](mailto:Mubarakhassan7@gmail.com), +2348161606567

Received on: October, 2025

Revised and Accepted on: November, 2025

Published on: December, 2025

## ABSTRACT

This study applied regression-based predictive modeling to estimate fish growth and yield performance in twelve semi-intensive ponds at the Federal College of Education (Technical), Gusau, Nigeria. Water quality indicators (temperature, dissolved oxygen, ammonia, pH), feed quantity, and stocking density were evaluated as key predictors of mean body weight, survival, and total biomass of *Oreochromis niloticus* and *Clarias gariepinus*. A repeated-measures design was used, with 20 fish sampled per pond every two weeks throughout the 11-month study period. Linear regression revealed strong positive effects of temperature, dissolved oxygen, feed amount, and pH on growth, while stocking density had a negative influence. Logistic regression showed that dissolved oxygen increased survival likelihood, whereas ammonia and high stocking density significantly reduced survival probabilities. The mixed-effects model demonstrated the highest predictive capability, indicating notable pond-level variation due to micro-environmental differences despite uniform management. Model comparison results confirmed that incorporation of random pond effects improved accuracy ( $R^2 = 0.91$ ) over standard linear and logistic models. These findings demonstrate the potential utility of regression-based models for improving decision-making in semi-intensive freshwater aquaculture systems.

**Keywords:** Aquaculture, Regression Modeling, Growth Prediction, Stocking Density, Dissolved Oxygen

## 1.0 INTRODUCTION

Aquaculture has become one of the fastest-growing areas in global food production. It plays a key role in tackling food security issues, boosting economic growth, and supporting rural communities (FAO, 2022; Naylor *et al.*, 2021). This sector is especially important in sub-Saharan Africa. Here, aquaculture offers a vital source of high-quality animal protein for millions. It not only improves nutrition but also helps reduce poverty and create jobs. In Nigeria, freshwater aquaculture has drawn considerable interest. Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) are among the most commonly farmed species. They are favored for their adaptability, fast growth, and strong market demand (Abubakar *et al.*, 2025; Olagunju *et al.*, 2022).

Despite the significant potential of aquaculture to meet rising protein needs, the practice remains complex and challenging. The growth, survival, and yield of farmed fish depend on many factors that include environmental, biological, and management aspects. Key environmental factors like water temperature, dissolved oxygen (DO), pH, and ammonia concentration are crucial for the fish's physiological performance and metabolic rates (Tashim *et al.*, 2025; Chen *et al.*, 2019; Sarif *et al.*, 2025). At the same time, management factors, such as feed composition, feeding frequency, pond stocking density,

and regular pond management practices, interact with environmental conditions to impact growth and overall productivity. Poor estimation or monitoring of these factors can lead to overfeeding or underfeeding, wasted resources, higher production costs, and increased mortality. These issues threaten both profitability and food security goals (Bar & Radde, 2020; Abiodun & Wreford, 2025).

Traditionally, aquaculture management has used hands-on knowledge and basic statistical analyses to make operational decisions. However, these methods often do not address the complex, nonlinear, and layered interactions found in pond-based aquaculture systems. This can lead to poor predictions and ineffective management actions (Ozor *et al.*, 2024; Mbachu *et al.*, 2024). Regression-based modeling provides a strong quantitative framework to overcome these issues. It allows for the simultaneous assessment of multiple factors and produces useful, data-driven predictions. Linear regression models work well for forecasting continuous results, like weight gain and total biomass. Generalized linear models (GLMs) are suited for binary or count outcomes, such as survival and mortality rates. Mixed-effects models handle hierarchical structures, like fish grouped within ponds or tanks. They capture both



fixed and random effects (Kutner *et al.*, 2005; Faraway, 2016; McCullagh & Nelder, 1989).

Empirical studies have shown that regression-based methods work well in aquaculture systems. For example, Olagunju *et al.* (2022) used linear and logistic regression models to study Nile tilapia growth in Nigerian earthen ponds. They found that water temperature, dissolved oxygen, and feeding frequency significantly affect growth performance. Mbachu *et al.* (2024) used mixed-effects models to look at African catfish growth. They pointed out how stocking density and water management critically influence yield outcomes. Likewise, Ozor *et al.* (2024) used GLMs to investigate survival and mortality patterns in different environmental conditions. On a global level, Chen *et al.* (2019) showed that computational models can predict feed intake and growth in groups of fish. This illustrates how modern modeling techniques can capture nonlinear and interactive effects among several predictors.

Despite these advances, there are still significant knowledge gaps. Many existing studies rely on small-scale or localized datasets, which limits how well predictive models apply to different aquaculture systems (Sarif *et al.*, 2025; Abiodun & Wreford, 2025). In addition, few studies evaluate the relative importance of various factors related to growth, survival, and yield outcomes. This leaves farm managers with little evidence-based guidance for improving management practices (Tashim *et al.*, 2025; Mbachu *et al.*, 2024). There is also a lack of studies that combine growth, yield, and survival outcomes in one modeling framework. This integration is crucial for effective aquaculture management.

The current study aims to fill these gaps by creating regression-based predictive models for Nile tilapia and African catfish at the College Fish Farm, Federal College of Education (Technical), Gusau, Zamfara State, Nigeria. The study focuses on three main goals: (i) identifying key environmental, feeding, and management factors that affect growth and survival, (ii) assessing the performance of regression models using standard statistical measures like  $R^2$ , RMSE, and residual diagnostics, and (iii) producing practical insights to support decision-making on the farm and improve production efficiency.

This study contributes in two ways by combining rigorous statistical modeling with realistic aquaculture management considerations. From a methodological standpoint, it shows how useful regression frameworks are for capturing intricate relationships between environmental factors, management strategies, and fish growth dynamics. In practical terms, it offers evidence-based suggestions to guide feeding plans, stocking density choices, and water quality control, ultimately

assisting profitable, efficient, and sustainable aquaculture operations in Nigeria and other tropical freshwater systems.

## 2.0 MATERIALS AND METHODS

### 2.1 Study Area and Fish Species

The study was conducted at the Fish Rearing Center, Department of Agricultural Education, Federal College of Education (Technical), Gusau, Zamfara State, Nigeria (12.1716°N, 6.6697°E). The area is characterized by a tropical savanna climate with mean annual temperatures ranging from 22 to 37°C and annual rainfall between 800 and 1,200 mm (NIMET, 2022). The farm operates twelve (12) semi-intensive ponds (eight earthen and four concrete) managed under uniform feeding and water quality regimes, in which Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) are cultured due to their economic importance and adaptability to Nigerian freshwater systems (Abubakar *et al.*, 2025; Olagunju *et al.*, 2022). Fish growth and survival were monitored using a repeated-measures design, in which the same cohorts of fish in each pond were measured at regular intervals throughout the culture period.

### 2.2 Data Collection

The research data collection spanned 11 months from January to November 2025 at the Fish Rearing Center, Department of Agricultural Education, Federal College of Education (Technical), Gusau. Standard aquaculture sampling procedures (Boyd & Tucker, 2012) were used to measure growth and yield indicators, including body weight, total length, total biomass, and survival rate at two-week intervals. Representative fish samples covering different size classes in each pond were collected using cast nets.

Water quality parameters were measured at three fixed locations (inlet, midpoint, and outlet) during the 07:00–09:00 period to standardize measurements and minimize the influence of diurnal fluctuations, thereby ensuring comparability across sampling dates and ponds.

Management data, including stocking density, feed quantity, feeding timing, and pond dimensions, were recorded throughout the study period. Commercial floating pellets were used to feed *Oreochromis niloticus* and *Clarias gariepinus* under semi-intensive culture conditions. This standardized data collection approach provided reliable inputs for regression-based prediction of growth and yield performance.

### 2.3 Regression Model Specification and Data Analysis

Regression modeling was used to predict the growth and yield performance of *Oreochromis niloticus* and *Clarias gariepinus* based on water quality parameters, feed input, and stocking density. Model estimation, assumption checking, and validation diagnostics were conducted

using R software. Normality and homoscedasticity were assessed using residual distribution and Q-Q plots, independence was verified through residual autocorrelation checks, and multicollinearity among predictors was evaluated using variance inflation factors (VIF), with all VIF values < 5, indicating no serious multicollinearity. Model performance was evaluated using R<sup>2</sup>, RMSE, AIC, and residual diagnostics to assess goodness of fit and predictive accuracy (Kutner et al., 2005; Faraway, 2016; McCullagh & Nelder, 1989).

### 2.3.1 Linear Regression Model for Growth Prediction

Fish growth (mean body weight) was modeled as a continuous response variable influenced by environmental and management factors. The general linear regression form is:

$$Y_i = \beta_0 + \beta_1 Temp_i + \beta_2 DO_i + \beta_3 Feed_i + \beta_4 Stock_i + \beta_5 pH_i + \varepsilon_i \quad (1)$$

Where,  $Y_i$  = mean fish weight/biomass (g) at time  $i$ ,

$Temp_i$  = water temperature (°C),  $DO_i$  = dissolved

oxygen (mg/L),  $Feed_i$  = total feed ration (g/day),  $Stock$

$i$  = stocking density (fish/m<sup>2</sup>),  $pH_i$  = pond water pH and

$\varepsilon_i$  = model error term.

This model enabled prediction of biomass gain in response to varying pond conditions and feeding patterns, consistent with empirical findings by Olagunju *et al.* (2022) and Mbachu *et al.* (2024).

### 2.3.2 Logistic Regression for Survival Rate

Survival probability was modeled using a generalized linear model with a logit link due to the binary nature of survival outcomes. The model expression is:

$$\log it(P_i) = \ln\left(\frac{P_i}{1-P_i}\right) = \alpha_0 + \alpha_1 Temp_i + \alpha_2 NH_3 + \alpha_3 DO_i + \alpha_4 Stock_i \quad (2)$$

Where:  $P_i$  = probability of fish survival, and  $NH_3$  = ammonia concentration (mg/L).

This formulation aligns with aquaculture mortality modeling approaches presented by Ozor *et al.* (2024) and Chen *et al.* (2019).

### 2.3.3 Mixed-Effects Model for Pond Hierarchical Structure

Due to fish being reared across different ponds with potential environmental variation, a mixed-effects model was applied to account for pond-level random effects:

$$Y_{ij} = \beta_0 + \beta_1 X_{ij} + \mu_j + \varepsilon_{ij} \quad (3)$$

Where:  $Y_{ij}$  = growth response of fish  $iii$  in pond  $j$ ,  $X_{ij}$  = vector of predictor variables (DO, feed rate, temperature, stocking density),  $\mu_j$  = random effect attributed to pond  $j$  (unobserved conditions),  $\varepsilon_{ij}$  = residual error.

This structure improves prediction accuracy under semi-intensive culture systems typical of Nigerian freshwater farms (Abubakar *et al.*, 2025; Sarif *et al.*, 2025).

## 3.0 RESULTS

### 3.1 Descriptive Statistics of Water Quality and Growth Variables

Table 1: Descriptive Statistics of Water Quality and Growth Parameters

Parameter	Mean	Minimum	Maximum	Standard Deviation
Temperature (°C)	28.6	22.3	34.8	3.21
Dissolved Oxygen (mg/L)	5.41	3.20	7.85	1.54
pH	7.32	6.40	8.10	0.42
Ammonia (mg/L)	0.21	0.04	0.62	0.09
Nitrate (mg/L)	7.83	3.10	13.50	2.14
Stocking Density (fish/m <sup>2</sup> )	12.1	9.0	15.0	1.87
Mean Weight (g)	203.5	35.0	411.0	89.2
Survival Rate (%)	88.4	72.0	96.0	6.54
Total Biomass (kg/pond)	54.6	22.9	97.4	17.6

The water quality together with pond conditions created suitable conditions for Nile tilapia and African catfish farming. The water conditions included proper temperature and oxygen levels and pH values and safe ammonia and nitrate concentrations. The pond maintained suitable stocking density which enabled proper growth of fish while achieving 203.5 g average weight and 88.4% survival rate and 54.6 kg total biomass per pond.

### 3.2 Linear Regression Results for Growth Prediction

Table 2: Regression Coefficients for Mean Weight Prediction

Predictor	Coefficient (β)	Std. Error	t-value	p-value
Intercept	-112.34	41.50	-2.70	0.009*
Temperature	4.92	1.20	4.10	0.001*
Dissolved Oxygen	7.83	2.15	3.64	0.002*
Feed Quantity	0.062	0.019	3.27	0.004*

Stocking	-2.87	1.08	-2.65	0.011*
Density				
pH	6.45	2.92	2.21	0.028*

\*Significant at  $p < 0.05$

The linear regression results demonstrate that temperature and dissolved oxygen and feed quantity and pH levels directly affect fish growth because their increased values lead to weight gain. The research shows that higher stocking density leads to negative growth effects because fish eat less when they are crowded. The model successfully explained 89% of mean weight variation through its  $R^2$  value of 0.89 while maintaining a low prediction error of 14.72 g.

### 3.3 Logistic Regression Results for Survival

**Table 3: Logistic Regression Output for Survival Probability**

Predictor	Coefficient ( $\alpha$ )	Std. Error	p-value	Odds Ratio
Intercept	1.82	0.55	0.003*	—
Temperature	0.124	0.041	0.006*	1.13
Dissolved Oxygen	0.265	0.083	0.002*	1.30
Ammonia	-0.341	0.090	0.001*	0.71
Stocking Density	-0.113	0.047	0.012*	0.89

\*Significant at  $p < 0.05$

The logistic regression analysis shows that fish survival becomes more likely when temperature rises and dissolved oxygen levels increase while dissolved oxygen raises survival chances by 30% for each mg/L increase. The survival chances of fish decrease when ammonia levels rise and when the fish population becomes too dense but ammonia stands out as the main cause of death. The research demonstrates that fish survival depends on both proper water quality management and correct fish population numbers.

### 3.4 Mixed-Effects Model Results

**Table 4: Random Effects Summary (Pond-Level Variability)**

Component	Std. Dev.
Pond Random Effect ( $u_{pond}$ )	11.28
Residual Error ( $\epsilon$ )	9.64

The mixed-effects model showed significant pond-level differences because the random pond effect standard deviation reached 11.28. The model shows that fish growth depends heavily on pond-specific factors including shade and algal bloom and silt load even when feeding and stocking remain constant. The results confirm that predictive models in aquaculture need to include pond-specific factors which supports the application of hierarchical modeling approaches.

### 3.5 Model Comparison Summary

Model	$R^2$ / Pseudo- $R^2$	RMS E	AIC	Key Use
Linear Regression	0.89	14.72	286.4	Weight/Biomass
Logistic Regression	0.72	—	145.2	Survival Prediction
Mixed-Effects Model	0.91	12.10	271.8	Pond Variation Control

The comparison of model performance revealed that the mixed-effects model had the highest predictive accuracy ( $R^2 = 0.91$ , RMSE = 12.10, AIC = 271.8). It outperformed both linear regression ( $R^2 = 0.89$ , RMSE = 14.72) and logistic regression (Pseudo- $R^2 = 0.72$ , AIC = 145.2). This shows that considering pond-level variation helps to better predict growth and biomass. It emphasizes the benefits of hierarchical modeling in semi-intensive aquaculture systems.

## 4.0 DISCUSSION OF RESULTS

The findings of this study show the complex relationship between environmental conditions, management practices, and biological responses in semi-intensive aquaculture systems at the Fish Rearing Center, Federal College of Education (Technical), Gusau, Zamfara State. The analysis revealed that fish growth, survival, and yield are significantly affected by water quality parameters, feeding strategies, and stocking density. This confirms that aquaculture production is a process influenced by multiple factors that require careful monitoring and management.

Water quality parameters were identified as key factors for growth and survival. Linear regression results showed that temperature and dissolved oxygen had a significant and positive impact on mean body weight and biomass accumulation. These findings support existing studies that suggest optimal thermal conditions increase metabolic rates, protein synthesis, and feed conversion efficiency in fish (Chen *et al.*, 2019; Olagunju *et al.*, 2022). The average pond temperature was 28.6°C, and the dissolved oxygen concentration was 5.41 mg/L. Both figures were within the physiological tolerance ranges for *Oreochromis niloticus* and *Clarias gariepinus*, allowing for continuous growth during the culture period. This observation emphasizes the importance of maintaining stable water quality to support metabolic activity and enhance growth potential, as previously noted by Boyd and Tucker (2012) and Bar and Radde (2020).

Feeding and stocking density were also important factors influencing growth and survival. The amount of feed positively affected mean weight, showing that proper and consistent feeding improves growth rates, which aligns



with studies by Ozor *et al.* (2024) and Mbachu *et al.* (2024). In contrast, stocking density had a negative impact on growth and survival. This reflects stress from density, competition for resources, and possible oxygen depletion in the pond environment. These results confirm earlier findings that overcrowding limits feed intake, decreases growth efficiency, and raises the risk of mortality (Mbachu *et al.*, 2024; Sarif *et al.*, 2025). The negative effects of high stocking densities also stress the need to match the number of fish with pond capacity and environmental limits to improve production results.

Logistic regression results highlighted how water quality affects survival chances. Dissolved oxygen raised survival odds by about 30% for each mg/L, while ammonia and higher stocking density significantly lowered the chances of survival. Although ammonia levels were fairly low, even small increases were linked to reduced survival. This supports earlier work that found ammonia toxicity to be a major issue in semi-intensive pond aquaculture (Abiodun & Wreford, 2025; Ozor *et al.*, 2024). The serious effect of ammonia points to the necessity for careful management of feed, waste, and water changes to reduce toxic build-up and maintain healthy pond conditions.

The application of mixed-effects modeling showed a large amount of pond-level variation, suggesting that small-scale environmental differences (e.g. distribution of algae patches, sediment accumulation and patterns of shading) likely caused differential growth responses among ponds. The high random effect at the pond level highlights that even between ponds exposed to standard management practices, there are specific local environmental conditions influencing fish performance. This result supports the hierarchical modeling concept proposed by Chen *et al.* (2019) and Abubakar *et al.* (2025), supporting that statistical models for aquaculture need to consider fixed and random factors of variation to obtain precise and reliable predictions.

Collectively, the mixed-effects model performed best in terms of prediction accuracy, while linear and logistic regressions for growth and survival provided lower accuracy highlighting the requirement to select appropriate models depending on response type and data structure. The high  $R^2$  and low RMSE realized in the present study showed that regression-based techniques are relatively good tools for forecasting growth and yield, which is a basis for making decision in aquaculture systems. Residual diagnostics verified the model assumptions were adequate and help build confidence in the robustness of these prediction models.

In practical terms, the results have several implications for aquaculture management. Management operations such as pre-feeding water quality (especially dissolved oxygen), the size of shrimp populations in relation to pond volume, feeding rates relative to metabolic demand

and measurement of ammonia are key components for the maximization of growth and survival potential. Additionally, the pond-level variation demonstrated here underscores the necessity for managers to consider site-specific information when designing interventions or developing production estimates. These findings agree with the suggestions of Tashim *et al.* (2025) and Sarif *et al.* (2025); focusing on the merging of data-driven predictive models with in situ monitoring to achieve efficient farm-level management.

Although the regression models demonstrated strong predictive performance, their applicability is limited to semi-intensive pond-based aquaculture systems under tropical climatic conditions. The relationships identified in this study may not be directly transferable to intensive or recirculating aquaculture systems, where water exchange rates, stocking densities, and management practices differ substantially. Thus, caution should be exercised when generalizing these findings beyond similar production environments.

In summary, fish growth, survival and yield in semi-intensive culture aquaculture are found to be influenced by a mixture of the environmental parameters as well as feeding and management practices. Regression-based modelling, especially mixed-effects models, can provide a statistically robust method for quantifying these relationships and thereby underpinning evidence-based decisions, resulting in increased productivity and profitability of freshwater aquaculture systems.

## 5.0 CONCLUSION

This result indicates that the water quality, feed management and stocking density are important in fish growth, survival and production continuously in a semi-intensive aquaculture. Various regression modeling, including linear, logistic and mixed-effects models were successfully used to model the relationships among environmental and management factors and important aquaculture responses. Temperature, DO and feed amount were the most significant positive contributors to growth, while high stocking density and ammonia were negatively associated with survival and performance. The random-effects model also showed that variability among ponds plays a significant role in driving discrepancies in fish growth, highlighting the importance of accounting for local environmental conditions when making management decisions. In general, this study demonstrates that predictive modeling can be used as a powerful tool to gain insight into and optimize aquaculture performance in a quantifiable manner, which would beneficially impact productivity and sustainability.

## 6.0 RECOMMENDATIONS

- i. Keep Ideal Water Conditions: Regular testing and correction of important water features such as DO, pH, temperature and ammonia should be focused on maintaining positive setting for good fish growth and survival.
- ii. Feeding Management: Adjust feeding rates according to fish growth and biomass in order to minimize feed losses and water quality impairment. Scheduled feeding programmes can be implemented to improve efficiency of growth.
- iii. Maximize Stocking Densities: To minimize competition and stress, both of which reduce growth and survival - overstocking should be avoided. Stocking rates need to be adapted according to pond type, fish species, and carrying capacity.
- iv. Tackle Pond-Level Heterogeneity: Managers should manage each pond differently to address the differences among ponds (of microenvironmental variables, for example), so as to achieve consistent growth or yield (the same level of production).
- v. Include Predictive Modeling in Farm Management: Nutritional and pond management (2, 3) decisions should daily be based on simple tools like regression to predict growth or survival.
- vi. Suggested Future Research: By incorporating more species and different farms, as well as real-time environmental monitoring into predictive studies, model robustness will increase and become applicable to broader ranges of management practices in aquaculture

## REFERENCES

- Abiodun, B., & Wreford, A. (2025). Impacts of water quality and management practices on freshwater aquaculture productivity. *Journal of Aquaculture Management*, 18(2), 101–115.
- Abubakar, M., Ahmed, S., & Bello, T. (2025). Growth performance and yield of Nile tilapia and African catfish in semi-intensive pond systems in Nigeria. *African Journal of Fisheries Science*, 12(1), 45–58.
- Bar, N. S., & Radde, N. (2009). Long-term prediction of fish growth under varying ambient temperature using a multiscale dynamic model. *BMC Systems Biology*, 3, 107. <https://doi.org/10.1186/1752-0509-3-107>
- Bar, N. S., & Radde, N. (2020). Mechanistic modeling of fish growth for aquaculture applications. *Computational Biology Reports*, 7(3), 215–230.
- Boyd, C. E., & Tucker, C. S. (2012). *Pond aquaculture water quality management* (2nd ed.). Springer.
- Chen, Y., Liu, P., & Zhang, X. (2019). Predicting feed intake and growth in grouped fish populations using computational models. *Aquaculture Research*, 50(5), 1345–1357. <https://doi.org/10.1111/are.14125>
- FAO. (2022). *The state of world fisheries and*

- aquaculture 2022: Towards blue transformation*. Food and Agriculture Organization of the United Nations. <http://www.fao.org/fishery/sofia>
- Faraway, J. J. (2016). *Linear models with R* (2nd ed.). CRC Press.
- Kutner, M. H., Nachtsheim, C. J., Neter, J., & Li, W. (2005). *Applied linear statistical models* (5th ed.). McGraw-Hill/Irwin.
- Mbachu, C., Udo, O., & Eze, K. (2024). Mixed-effects modeling of African catfish growth under semi-intensive culture conditions. *Aquaculture Modeling Journal*, 11(2), 78–92.
- McCullagh, P., & Nelder, J. A. (1989). *Generalized linear models* (2nd ed.). Chapman & Hall.
- Naylor, R., Hardy, R., & Buschmann, A. (2021). Aquaculture and global food security: Prospects and challenges. *Nature Food*, 2(4), 217–226. <https://doi.org/10.1038/s43016-021-00241-4>
- NIMET. (2022). *Climate data for Zamfara State, Nigeria*. Nigerian Meteorological Agency. <https://www.nimet.gov.ng>
- Olagunju, F., Adewale, O., & Hassan, M. (2022). Regression analysis of growth and survival in Nile tilapia under earthen pond conditions. *Journal of Aquaculture Science*, 17(3), 201–215.
- Ozor, N., Musa, S., & Bello, H. (2024). Survival and mortality patterns in semi-intensive aquaculture: A generalized linear regression approach. *Aquaculture Analytics*, 9(1), 33–47.
- Sarif, M. I., Efendi, S., Sihombing, P., & Mawengkang, H. (2025). Mathematical modeling of water quality dynamics in aquaculture: A foundation for IoT integration and machine learning-driven predictive analytics. *Journal of Applied Data Sciences*, 6(3), 2221–2234. <https://doi.org/10.47738/jads.v6i3.819>
- Tashim, N. A. Z., Lim, T. H., Zariful, W., & Liu, P. (2025). Regression-based artificial intelligence length and weight estimation for sustainable prawn aquaculture. *Smart Agricultural Technology*, 12, 101089. <https://doi.org/10.1016/j.atech.2025.101089>