



Journal of Science, Technology and Innovation Research

Special Issue 2 | June 2026

Bridging Sustainability and Profitability: A Case Study of A Small-Scale Aquaponics Model

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ABSTRACT

Aquaponics is a sustainable and resource-efficient approach to food production. It combines aspects of aquaculture and hydroponics in a closed system where all nutrients are being recycled and very little waste is being produced (Goddek and Keesman, 2020; Rinehart, 2019). In this study, a small-scale aquaponics model was constructed using locally available materials. Twelve 50-L plastic tanks were connected to a central biofiltration unit and were used to rear 180 *Clarias gariepinus* juveniles for two months under controlled management conditions. The study evaluated the design, functionality and economic feasibility of the aquaponic model. The economic parameters considered include; construction and operational costs, revenue generation, and payback potential. The water quality parameters; temperature, dissolved oxygen, and pH obtained, were within optimal ranges, indicating effective system performance and filtration efficiency. The result showed a high initial setup cost of ₦800,000 and an operational cost of ₦40,000 per cycle; while the first production cycle had a gross revenue of ₦120,000, with a benefit-cost ratio (BCR) of 0.14. However, amortization analysis showed that the system will break-even after approximately ten production cycles, and improve profitability. This study revealed that; although starting small aquaponic setups demands high initial investment, long-term operation proves both practical and financially stable. Despite early expenses, these systems use nutrients more effectively, lose far less water than traditional methods - cutting usage by nearly 90% - while lowering supply needs via reuse. With time, such integration stands as a balanced approach: beneficial ecologically, feasible economically, suitable for growth within Nigerian contexts and similar regions.

Keywords: Aquaponics; Sustainable Agriculture; Economic Viability; Integrated Farming; Food Security

Introduction

With the growing global population and unpredictable shift in weather patterns, pressure builds on how food is grown. Commercial land-based cultivation

demands large plots of land and steady water flow; which are resources now harder to secure consistently across regions (Food and Agriculture Organization (FAO), 2021). Despite these limitations, evidence points to alternative models capable of operating with far less water waste/usage. Research as shown that up to ninety percent less water may be used when

doi.org/10.51459/jostir.2026.2.Special-Issue-1.0281

combining fish rearing with plant growth in closed-loop setups (Love *et al.*, 2015). This method; known as aquaponics, recycles nutrients between aquatic animals and crops without draining local supplies rapidly.

Aquaponics which is a combination of aquaculture with hydroponics, operates as a closed-loop method where water reuse stands central (Goddek *et al.*, 2019). From the fish excretion, essential nutrients are provided for plant growth and the vegetation filters the fluid before it returns toward the aquatic habitats (Rakocy *et al.*, 2020). This cycling causes a sharp decline in waste, moderate rise in efficiency and measurable reduction in pollution. Several experimental and pilot systems including those using locally available materials have demonstrated that small-scale aquaponics systems can be technically feasible and economically viable under appropriate conditions (Mudashiru *et al.*, 2025; Benjamin *et al.*, 2022). Yet in Nigeria, uptake stays minimal - not because of interest, but due to gaps in skills, high initial investment, and infrastructure constraints (Benjamin *et al.*, 2022).

This research examines a compact aquaponics setup, focusing on structure, operation and financial practicality. It provides insight into how farmers and institutions in Nigeria can adapt aquaponics for sustainable and profitable food production. Thus, the technical performance, water-management efficiency and cost-benefit dynamics of the aquaponic system were analyzed.

Methodology

The study was carried out at the Teaching and Research farm of the Department of Fisheries and Aquaculture Technology, Federal University of Technology, Akure, Nigeria.

System Design and Construction

A small-scale aquaponics model was constructed using locally available materials, to reduce cost and environmental impact while enhancing replicability and ease of maintenance. The materials used in the construction included PVC pipes, a surface pump, plastic tanks, gravel for biofiltration, aeration tubing, and a wooden support frame. The structural layouts of this design are shown in Figures 1a and 1b.

Twelve (12) pieces of 50 L transparent plastic tanks were arranged on a reinforced wooden frame and connected to a central biofiltration unit through 25 mm (diameter) PVC pipes to allow continuous water circulation. A 0.5hp surface pump (1200 L h⁻¹) was connected to the system to provide aeration and maintain water flow across.

The setup had separate inlet and outlet lines for efficient drainage and recirculation and all joints were sealed with non-toxic adhesive. The plumbing was tested for 24 hours before stocking to ensure no leakage.

Fish Stocking and Management

One hundred and eighty (180) *Clarias gariepinus* juveniles were stocked into the aquaponics system at a density of 15 fish per tank. The fish were acclimated for 24 hours before commencing feeding to reduce stress, after which they were fed twice daily (08:00hrs and 15:00hrs). The feed used was a commercial floating feed with 35 % crude protein and feeding was done at 3-5 % of the fish body weight with quantity adjusted weekly based on visual observation and average growth trend.

Optimal environmental parameters for *C. gariepinus* in recirculating systems were maintained throughout

the study using continuous aeration and periodic water checks as recommended by Masabni and Sink (2020) and Oladimeji *et al.*, (2023). Partial water replacement (10-15 %) was carried out weekly to maintain optimal water quality and remove accumulated solids.

Economic Evaluation

Expenditures incurred during the construction of the aquaponic model were documented and grouped into six major categories. These categories are: Carpentry works, Electrical installation, Filtration system, Plumbing Works, Structural design, and Aquaculture materials

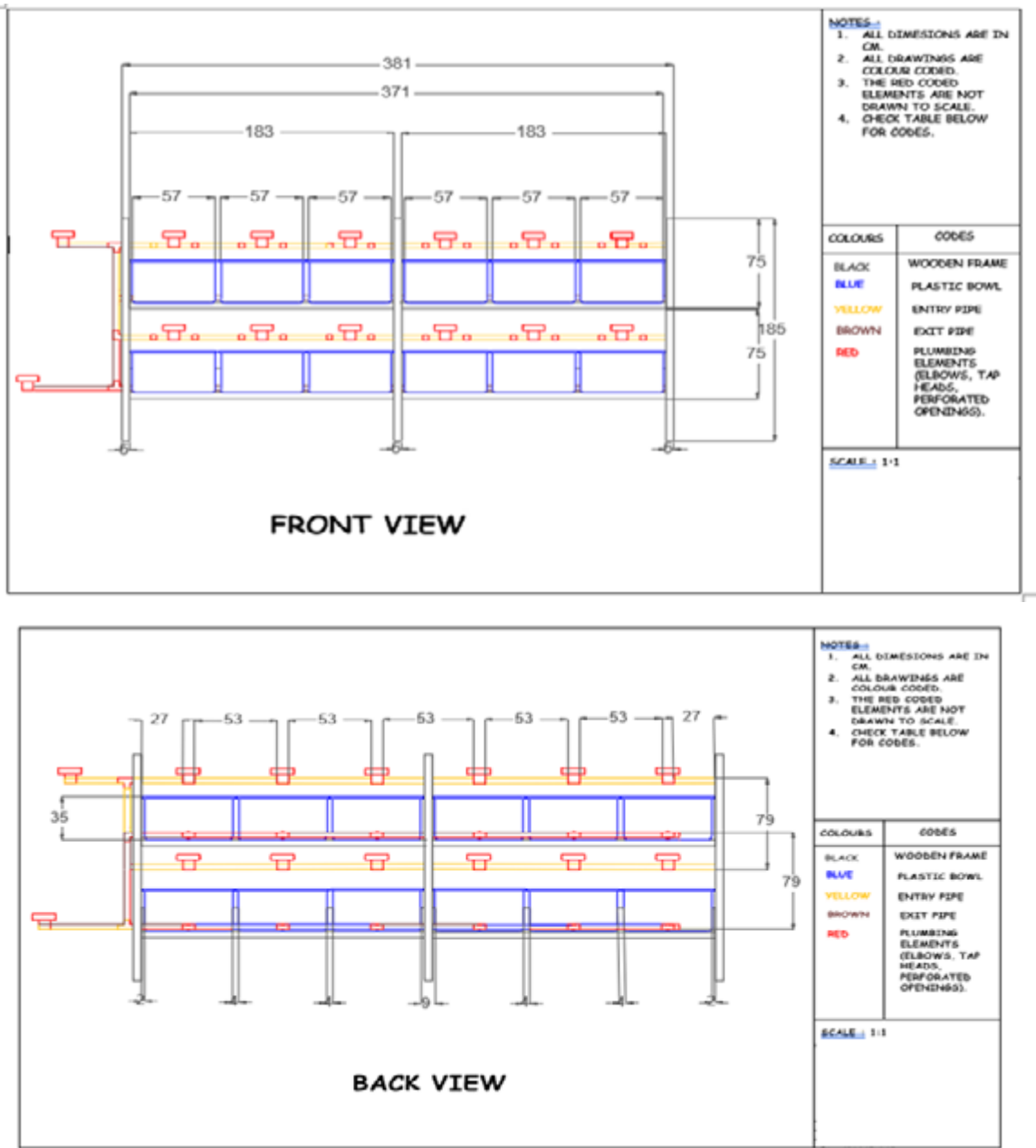


Figure 1a: Structural view (Front and back) of the Aquaponic setup

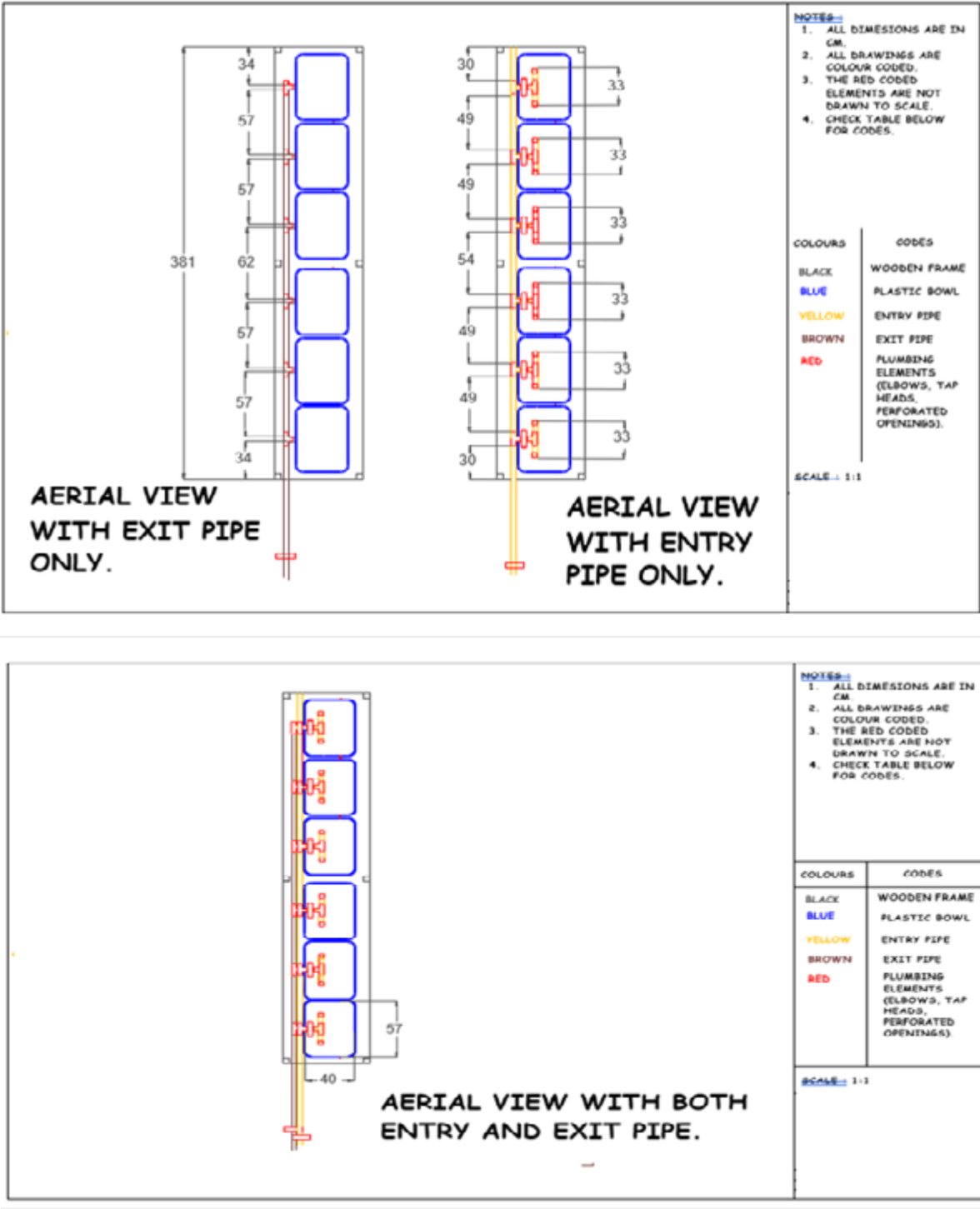


Figure 1b: Structural layout of the Aquaponic setup showing;

1. Aerial View of Aquaponics Setup Showing Entry pipe only and Exit Pipe only
2. Aerial Structural View of Aquaponics Setup Showing Both Entry and Exit Pipe

The economic performance of the project was analyzed to estimate the profitability of the system over several production cycles. Calculations considered the initial construction cost and operational expenses (feed, energy, and routine maintenance) against the projected fish revenue.

The economic evaluation principles as reported by *Oladimeji et al.* (2023) and *Shrestha and Shahi* (2023) were adopted to evaluate the economic performance of the aquaponics system:

$$\text{Total Cost (TC)} =$$

$$\text{Fixed Cost (FC)} + \text{Variable Cost (VC)} \quad (1)$$

$$\text{Gross Revenue (GR)} = \text{Average Fish Weight (kg)}$$

$$\times \text{Number of Fish Harvested} \times$$

$$\text{Market Price (₦ kg}^{-1}\text{)} \quad (2)$$

$$\text{Net Return (NR)} = \text{Gross Revenue (GR)}$$

$$- \text{Total Cost (TC)} \quad (3)$$

$$\text{Benefit - Cost Ratio (BCR)} = \text{Gross Revenue (GR)}$$

$$\div \text{Total Cost (TC)} \quad (4)$$

Note: A BCR greater than 1.0 indicates profitability, while a BCR less than 1.0 indicates loss.

Data Analysis

Data generated from system operation were analyzed using descriptive statistics (mean $\pm$ standard deviation). Water-quality, growth, and economic indicators were summarized in tables and graphs. All calculations were performed using Microsoft Excel 2021.

Results and Discussion

System Performance and Water Quality

Water quality obtained were within acceptable ranges for *Clarias gariepinus* (temperature 25-28 °C; DO $\geq$ 5 mg·L⁻¹; pH 6.8-7.5), indicating technical feasibility of the system design and effectiveness of the filtration (mechanical and biological) systems with continuous aeration. This corroborate with earlier reports that proper engineering and water management are essential for balanced aquaponics systems (*Rakocy et al.*, 2004; *Somerville et al.*, 2014).

Economic Evaluation

The financial analysis of the constructed aquaponics system was carried out to determine its profitability and long-term feasibility. The cost breakdown of the aquaponic system is presented in Table 1 while Figure 2 shows the percentage distribution of the construction cost components. The filtration system had the highest percentage (26.3%) of the construction cost while the structural design (3.8%) was the least. The total fixed cost of the system setup was ₦800,000, while the operating cost for the production cycle was ₦40,000.

One hundred and sixty (160) *C. gariepinus*; out of the 180 juveniles stocked, survived to harvest with an average harvested weight of 0.25 kg per fish, resulting in a total biomass of 40 kg. At the prevailing 2025 market rate of ₦3,000 kg⁻¹ for catfish, the gross revenue (GR) was calculated as:

$$GR = 160 \times 0.25 \times 3,000 = \text{₦120,000}$$

The total cost (TC) of production for the first cycle was calculated as:

$$TC = 800,000 + 40,000 = \text{₦840,000}$$

Figure 3 shows a comparison chart showing the total cost (comprising the fixed cost and variable cost) and the gross revenue.

Table 1. Cost breakdown for the aquaponics system

Categories	Items	Cost (₦)
Fixed Cost	Construction:	
	Carpentry works	150,000
	Electrical instal- lation	60,000
	Filtration system	210,000
	Plumbing Works	200,000
	Structural de- sign	30,000
	Aquaculture materials	150,000
	Total	800,000
Variable Cost	Operating Cost	40,000
Grand Total		840,000

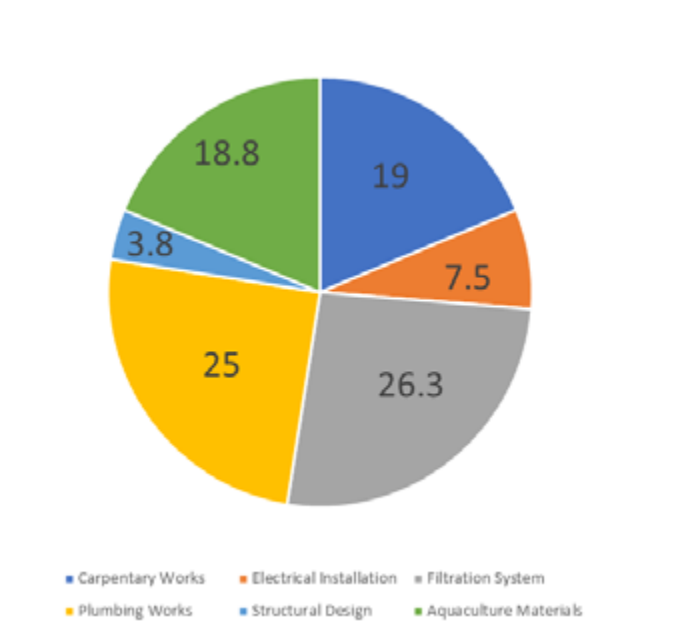


Figure 2: Percentage distribution of total construction costs for the aquaponics system.

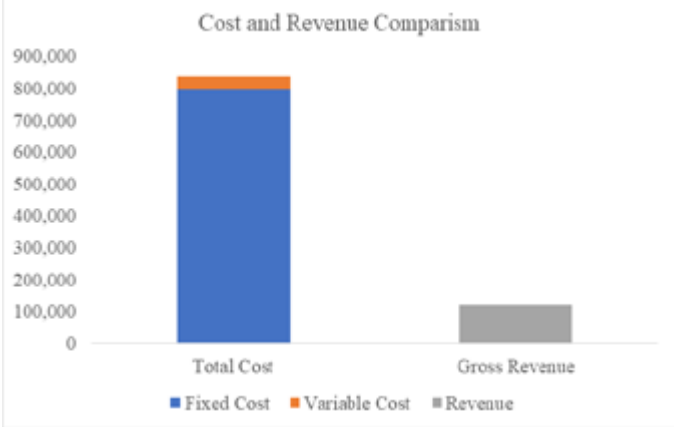


Figure 3: Comparison of total, fixed, and variable costs with gross revenue in the first production cycle.

The net return on investment (NR) and benefit-cost ratio (BCR) were calculated as:

$$NR = 120,000 - 840,000 = -\text{₦}720,000$$

$$BCR = \frac{120,000}{840,000} = 0.14$$

The low BCR (0.14) and negative net return (-₦720,000) obtained from the economic evaluation indicates that the system did not yield profit during the first production cycle and this can be linked to the high initial setup costs. In other to determine when the system is likely to break even, the economic evaluation was therefore amortized.

Amortized (Multi-Cycle) Analysis

The Fixed Cost (FC) was amortized across multiple cycles to estimate when the system breaks even and becomes profitable. The Per-cycle total cost when FC is spread over *n* cycles is given as:

$$TC_n = \frac{FC}{n} + VC$$
Solve for break-even cycles where

$$GR = TC_n$$

$$GR = \frac{FC}{n} + VC$$

$$n = \frac{FC}{GR - VC}$$

$$n = \frac{800,000}{120,000 - 40,000} = \frac{800,000}{80,000} = 10$$

Break-even occurs at 10 production cycles (i.e., after 10 cycles BCR $\approx$ 1.0).

$$TC_{(10)} = (800,000 \div 10) + 40,000 = \text{₦}120,000$$

and the BCR imp

$$BCR_{(10)} = \frac{120,000}{120,000} = 1.0$$

For $n > 10$, the per-cycle BCR > 0 .

The break-even cycle was calculated as 10 and the amortized BCR₍₁₀₎ value at this level was obtained as 1.0; indicating that the system will eventually break even after approximately ten production cycles. This reveals that long-term operation and reuse of the infrastructure will significantly enhance profitability, and agrees with findings of Benjamin *et al.* (2020) who reported that small-scale aquaponics is typically capital-intensive at inception but becomes profitable after multiple production cycles. The result also showed that if production efficiency can be improved through higher survival rates, increased harvest weight and reduced variable costs, the break-even point can be lowered, thereby accelerating cost recovery. These correspond with earlier reports that management optimization is vital for achieving sustainable profitability in small aquaponics systems (Rakocy *et al.*, 2004).

This study provides evidence that aquaponics is a technically viable and economically promising option for sustainable food production, as long as the systems are managed properly and operators receive appropriate training and support (Benjamin *et al.*, 2020; FAO, 2021). When viewed from a global perspective, aquaponics has great potential to support the development of more resilient, sustainable food systems in countries and communities around the world where water and/or land are limited (FAO, 2021). With the right combination of training, finance and policy support, such systems can be further improved for food security and environmental sustainability in Nigeria and the developing world

Conclusion

The results of this study demonstrated that aquaponic systems constructed with locally available materials in Nigeria can operate efficiently and sustainably if well managed. The amortization analysis also revealed that aquaponic system can be capital demanding at startup but can break even within a few production cycles. In conclusion, this research revealed aquaponics as a profitable and sustainable production system that integrates aquaculture and hydroponics, minimizes water use, and recycles nutrients.

Recommendations

Stakeholders including farmers, students and entrepreneurs should receive technical training and awareness on aquaponics management to enhance system efficiency and adoption. Government and development agencies should provide low-interest loans or grants to offset high setup costs and encourage early profitability.

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