Cost Efficiency and Sustainable Environmental Management in Catfish Production: Evidence from Anambra State, Nigeria

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Abstract

Growing production costs and increasing environmental concerns have intensified the need for aquaculture systems that are both economically efficient and environmentally sustainable. This study examined cost efficiency and sustainable environmental management performance (SEMP) among catfish producers in Anambra State, Nigeria. Specifically, it described producers' socio-economic characteristics, estimated profitability, determined cost efficiency and SEMP, examined the use of Sustainable Environmental Management (SEM) practices and the major production constraints. A multistage sampling procedure was employed to select 126 catfish producers, while data were collected using questionnaires and interview schedule. Data were analyzed using farm budgeting analysis, stochastic frontier cost function, the Proximity-to-Target Score Approach (PTSA), Probit regression and factor analysis. The results indicate that catfish production was not profitable, with a return on investment of −0.115. Mean cost efficiency is estimated to be 0.72, indicating that production costs could be reduced by 28% without reducing output. The community average of the SEMP index is estimated as 0.56, suggesting moderate environmental performance. Farming experience, extension contact and SEMP significantly influenced cost efficiency, whereas net income, farming experience and stocking density significantly influenced the use of SEM practices. The study concludes that achieving sustainable catfish production requires the simultaneous improvement of cost efficiency and environmental performance. Policies that strengthen extension services and expand access to affordable credit can support cost-saving production and investment in environmentally sustainable practices.

KEYWORDS: Cost Efficiency; Sustainable Environmental Management Performance; Catfish Production; Sustainable Environmental Management Practices; Anambra State

1.0 Introduction

Aquaculture has emerged as one of the fastest-growing food production systems and is increasingly recognized for its contribution to food security, nutrition and livelihood improvement, particularly in developing countries where demand for fish continues to rise with population growth, urbanization and changing dietary preferences (Food and Agriculture Organization, 2020; WorldFish, 2018). In Nigeria, catfish (*Clarias gariepinus*) accounts for the largest share of aquaculture production because of its rapid growth, adaptability and strong consumer preference (Anetekhai, 2017; Subasinghe *et al*., 2021). Yet, domestic fish production falls considerably short of national demand, creating an estimated supply deficit of 3.29 million metric tonnes and sustaining heavy reliance on fish imports (FAO, 2020; Federal Ministry of Agriculture and Rural Development, 2023). This production gap places greater responsibility on domestic aquaculture to expand output efficiently. Rising feed and fingerling costs, inflationary pressures, disease outbreaks and other production challenges have, nevertheless, increased operating expenses and reduced farm profitability (Ekunwe & Egware, 2015; Federal Ministry of Agriculture and Rural Development, 2023). Hence, pursuing cost-efficient production has become essential for improving the competitiveness of catfish enterprises. Equally important is the adoption of sustainable environmental management, as poor water quality management, feed losses, ineffective effluent disposal and weak biosecurity measures increase production costs, reduce farm productivity and expose the production environment to avoidable ecological risks (Md Noor & Harun, 2022; Ragasa *et al*., 2022). Consequently, environmentally responsible production practices are receiving greater attention as viable pathways for improving resource use, sustaining productivity and supporting long-term aquaculture development (Chukwuone *et al*., 2021; Lowanshi *et al*., 2024).

Despite growing interest in aquaculture efficiency and environmental sustainability, existing studies in Nigeria have largely examined production efficiency, profitability and sustainable environmental management as separately. While previous studies have estimated cost or technical efficiency, others have focused on the adoption of environmentally sustainable practices without assessing how environmental management performance relates to farm-level efficiency. This limits the evidence available for designing policies that can simultaneously improve producers' economic performance and environmental stewardship. The present study addresses this gap by integrating stochastic frontier cost analysis with sustainable environmental management performance assessment to examine the relationship between cost efficiency and environmental management among catfish producers in Anambra State, Nigeria. Beyond estimating cost efficiency, the study evaluated producers' environmental management performance, assessed the factors influencing the use of sustainable environmental management practices and identified the constraints affecting catfish production. The findings provide empirical evidence to support strategies aimed at promoting economically viable and environmentally sustainable aquaculture.

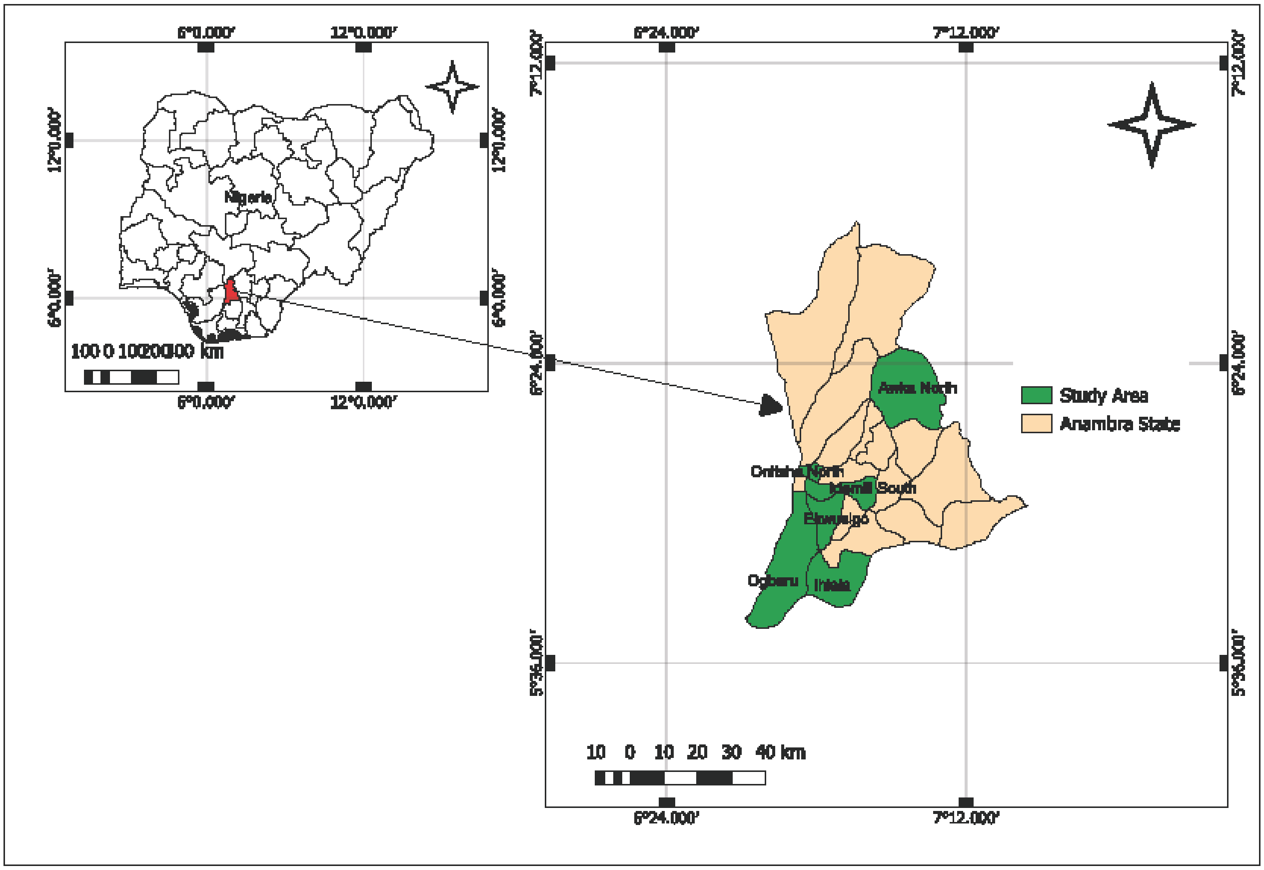
2.0 Materials and Methods

The broad objective of the study is to conduct the structural analysis of soybean marketing Niger State, Nigeria. The specific objectives of the study are to:

describe the socioeconomic characteristics of soybean marketers in the study area; and to analyze the structure of soybean marketers in the study area;

2.1 *Study Area*

The study was conducted in Anambra State, Nigeria, which lies between latitudes 5°35′N and 6°50′N and longitudes 6°35′E and 7°25′E. The State is one of the five states in the Southeast geopolitical zone of Nigeria. It shares boundaries with Delta State to the west, Imo and Rivers States to the south, Abia and Enugu States to the east, and Kogi State to the north. Anambra State occupies a land area of 4,844 km² and has a projected population of 6,953,500, an annual population growth rate of 2.2%**,** and a population density of 863 persons per km² (National Bureau of Statistics, 2025). The State experiences a humid tropical climate with an average annual rainfall of 2,500 mm and a mean annual temperature of 28.9°C (Nigeria Meteorological Agency, 2025), conditions that favour year-round agricultural production. Major crops cultivated include cassava, yam, maize, rice, cocoyam, vegetables and oil palm, while livestock enterprises comprise poultry, piggery, small ruminants and aquaculture, particularly catfish production. Anambra State is administratively divided into 21 Local Government Areas (LGAs) and possesses extensive inland water resources that support fish farming. Despite its agricultural potential, farming activities are frequently affected by environmental hazards, particularly flooding and gully erosion, which threaten agricultural land, infrastructure and rural livelihoods (Obi & Okechukwu, 2017; Egboka & Okoyeli, 2019).



Source: *DIVA-GIS DATA (2025).*
Figure 1*:* Map showing the selected study areas in Anambra State

2.2 Sampling Procedure and Data Collection

A multistage sampling procedure was employed to select catfish producers for the study. The first stage involved the purposive selection of the three agricultural zones in the State to ensure coverage of the major aquaculture producing areas In the second stage, two LGAs with high concentrations of catfish farming activities were purposively selected from each of the agricultural zones (Ogbaru, Ihiala, Ekwusigo, Onitsha North, Idemili South and Awka North) based on lists of registered and active catfish producers obtained from farmers' associations and Anambra State Agricultural Development Programme (ADP), which served as the sampling frame. The sampling frame contained 595 registered catfish producers, constituting the study population. In the final stage, 21 respondents were randomly selected from each of the LGAs, giving a total sample of 126 catfish producers who were interviewed for the study. Data were collected using a questionnaire administered through interview schedule and in-depth discussion.

2.3 Analytical Framework

Descriptive statistics were used to describe the socioeconomic characteristics of respondents. Farm budgeting analysis was employed to estimate the profitability of catfish production. Farm-level cost efficiency and its determinants were estimated using the stochastic frontier cost function with inefficiency effects. Sustainable Environmental Management Performance (SEMP) was estimated using the Proximity-to-Target-Score Approach (PTSA), while a binary Probit model was used to assess the factors influencing the use of sustainable environmental management practices. Principal Component Factor Analysis was applied to identify the major constraints affecting catfish production in the study area.

Farm Budgeting Analysis

The profitability of catfish production was estimated using farm budgeting analysis. The technique compares production costs with revenue generated from the enterprise and provides measures of financial performance, including gross margin, net farm income, operating ratio and return on investment. Chiekezie *et al.* (2023, Obianefo *et al.* (2020), and Olukosi and Erhabor (2008) estimated the profitability of farm enterprises as:

$$\bar{\wedge} = TR - TC \quad (1)$$

$$TC = TFC + TVC \quad (2)$$

$$TR = Py \times Q \quad (3)$$

$$GM = TR - TVC \quad (4)$$

$$NFI = TR - TC \quad (5)$$

$$ROI = NR/TC \quad (6)$$

Where: P_y = Price of output; $\bar{\wedge}$ = Total Profit; TC = Total Cost; TR = Total Revenue; Q = Output; P_y = Price per unit of output; TFC = Total Fixed Cost; TVC = Total Variable Cost; GM = Gross Margin; NFI = Net Farm Income; ROI = Return on Investment

Fixed cost was estimated as the total amount of depreciated assets. The study used Double Declining Balance depreciation method with a depreciation rate of 10% per annum.

Stochastic Frontier Cost Function

The model was specified in Cobb-Douglas functional form, with total production cost expressed as a function of output and input prices. The inefficiency effects model was simultaneously estimated as a function of selected socioeconomic, institutional and farm-specific characteristics, including Sustainable Environmental Management Performance (SEMP) index, to examine their influence on farm-level cost efficiency. Farm-level cost efficiency as proposed by Aigner *et al.* (1977), and Meeusen and Van den Broeck (1977) can be expressed as:

$$\ln \mathrm{TC} = \delta + \alpha \ln Q_i + \beta_1 \ln \mathrm{P}_1 + \beta_2 \ln \mathrm{P}_2 + \beta_3 \ln \mathrm{P}_3 + \beta_4 \ln \mathrm{P}_4 + \beta_5 \ln \mathrm{P}_5 + \beta_6 \ln \mathrm{P}_5 + \mathrm{V}_i + \mathrm{U}_i \quad (7)$$

Where: TC = Total Cost (naira); Q_i = Total quantity of catfish output of the i^{th} producer (kilogramme); P_1 = Price of fingerlings (naira); P_2 = Price of pond (naira); P_3 = Price of feed (naira); P_4 = Price of water (naira); P_5 = Price of labour (naira); P_6 = Price of fertilizer (naira); δ = Constant term; α = Catfish output coefficient; β_1 - β_6 = Parameter estimates; *ln* = Natural logarithm; v_i = Random error due to statistical noise which are outside the control of the catfish producers; u_i = Randomness due to cost inefficiency relative to the stochastic frontier.

The determinants of cost efficiency of catfish producers is specified as:

$$\sum [\exp(\mathrm{u}_i)] = \delta_0 + \delta_1 \mathrm{Z}_1 + \delta_2 \mathrm{Z}_2 + \delta_3 \mathrm{Z}_3 + \delta_4 \mathrm{Z}_4 + \delta_5 \mathrm{Z}_5 + \delta_6 \mathrm{Z}_6 + \delta_7 \mathrm{Z}_7 + \delta_8 \mathrm{Z}_8 \quad (8)$$

Where: u_i = Cost inefficiency of the i^{th} catfish producers; Z_1 = Age of the catfish producer (years); Z_2 = Level of education (number of years spent in school); Z_3 = Catfish farming experience (years); Z_4 = Household size (number of persons per head); Z_5 = Marital status (married = 1; single = 0); Z_6 = Cooperative membership (members = 1; non- member = 0); Z_7 = Extension Contact (number of times the producer visited extension personnel); Z_8 = SEMP Index; δ_0 = Constant; δ_1 - δ_8 = Parameter estimates.

Cost efficiency indices were derived from the estimated frontier model and ranged from zero to one, with values closer to unity indicating higher levels of cost efficiency.

Sustainable Environment Management Performance

Sustainable Environmental Management Performance (SEMP) was assessed using the Proximity-to-Target-Score Approach (PTSA), as adopted by the Ecologic Institute for International and European Environmental Policy (2018). The approach estimates producers' environmental management performance by comparing the observed level of compliance with established environmental management targets across selected sustainability indicators (analogous to SEM practices). The indicators comprised responsible brood stock sourcing, measures for disease and parasite prevention, water quality management, effluent management, efficient water use, mitigation of impacts on wild fish populations, adoption of energy-efficient practices and compliance with environmental regulations. They are presented in Table 1 below;

Table 1: Sustainable Environmental Management Performance Indicators for Catfish Production

Category	**Indicators**
Responsible Sourcing of Brood Stock	• Procure fish seeds from registered/recognized sources

Reduction in Disease and Parasite Transmission	• Implement biosecurity measures • Site ponds far from flood prone areas • Site ponds away from disease sensitive areas • Clean ponds after each production cycle
Effective Effluent Management	• Treat waste/water before disposing • Avoid overcrowding of catfish • Responsible use of antibiotics and aqua-chemicals • Have strategies for reducing waste build up in the pond
Water Quality Control	• Measure dissolved oxygen in water • Measure water P^H and water temperature • Frequently changing water in the pond
Mitigation of Aquaculture Impacts on Wild Fish Population	• Have no fish escape from ponds
Efficient Production and Water Circulatory Systems	• Implement integrated aquaculture • Increase pond dyke heights • Use of ponds with flow-through or re-circulatory systems • Use of proper pond design to maximize natural sunlight exposure • Proper drainage systems
Energy Efficient Measures	• Use of energy efficient aeration systems • Use of renewable energy sources such as: solar to power pumps and other equipment
Compliance with Environmental Regulations	• Adherence to local and national environmental regulations

Source: *Yacout et al. (2025); Aly and Fathi (2024); Lowanshi et al. (2024); Ojewole et al. (2024); Md Meffahul et al. (2023); Ragasa et al. (2022); Chukwuone et al. (2021)*

The study used a total of 21 indicators obtained through extensive literature review. These indicators were normalized into a proximity-to-target-score using the formula:

$$X_{ik\ normalized} = \frac{X_{ik} - Min\ (X_k)}{Max(X_k) - Min(X_k)} \quad (9)$$

Where: $X_{ik\ normalized}$ = Normalized value (transformed score) of ith catfish producer for indicator k

X_{ik} = Value of ith catfish producer for indicator k; $Min(X_k)$ = Lowest value of indicator k; $Max(X_k)$ = Highest value of indicator k

A 5-Point Likert Scale - very strong (5), strong (4), moderate (3), weak (2) and very weak (1) - was used to obtain the indicator scores for each catfish producer. It was constructed such that the lowest ($Min(X_k)$) and the highest scores ($Max(X_k)$) was obtained from the responses of catfish producers on each of the indicators of SEM practices employed. These normalized indicator scores were aggregated to generate a composite SEMP Index for each producer using simple average method, computed as:

$$SEMP_{iIndex} = \frac{\sum X_{in\ normalized}}{N} \quad (10)$$

Where: $SEMP_{iIndex}$ = Sustainable environmental management performance index of ith catfish producers; $\sum X_{in\ normalized}$ = Sum of the normalized values of the n selected indicators of the ith catfish producer; N = Number of selected SEM indicators considered.

This study adopted the approach of Moreno-Miranda and Dries (2022), and Gomez, Kelly, Syers and Coughian (2015). The approach uses the community average method to establish a cut-off point that represents the boundary between poor sustainability and good sustainability performance in the context of environmental management practices employed. This seems reasonable since farmers commonly judge their performance on the basis of their position relative to their counterparts.

Determinants of the use of Sustainable Environmental Management Practices

The factors influencing the use of SEM practices were analyzed using a binary Probit regression model. Prior to estimation, a SEM Practices adoption variable was constructed from the identified environmental management practices. Producers who scored 50% and above were considered as meeting the adoption threshold and as such were coded 1, while those below the threshold were coded 0. The resulting binary dependent variable was then regressed on selected socioeconomic, institutional and farm-level characteristics to assess the probability of using sustainable environmental management practices. Following Chukwuone *et al*. (2021) and Alabi *et al.* (2014), the Probit model is expressed as:

$$Y^* = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + u_i \quad (11)$$

$Y_i = 1$ if $Y_i^* > 0$; $Y_i = 0$ if $Y_i^* \leq 0$

Where: Y_i^* = Use of SEM practices (1 = use SEM practices; 0 = if otherwise); X_1 = Net income of catfish producer; X_2 = Age of catfish producer (years); X_3 = Number of years spent in school; X_4 = Catfish farming experience (years); X_5 = Household size (number of persons per head); X_6 = Gender (male = 1; female = 0); X_7 = Number of production cycles per year; X_8 = Number of fingerlings stocked; X_9 = Extension contact (number of times the producer visited extension personnel); β_0 = Constant term; $\beta_1 - \beta_9$ = Parameter coefficients; U_i = error term, which is normally distributed with a 0 mean and equal variance.

Factor Analysis

The major constraints affecting catfish production were identified using Principal Component Factor Analysis with Varimax rotation. Factors with eigenvalues greater than one were retained for interpretation, while variables with relatively high factor loadings (≥ ±0.4) were used in naming the extracted factors. Principal Component Analysis as used by Aroyehun and Henri-Ukoha (2021) is specified as:

$$PC_1 = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1n}X_n$$

$$PC_2 = a_{21}X_1 + a_{22}X_2 + \cdots + a_{2n}X_n$$

$$\begin{matrix} . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \end{matrix}$$

$$PC_n = a_{n1}X_1 + a_{n2}X_2 + \cdots + a_{nn}X_n \quad (3.20)$$

Where; PC_1, PC_2, ... PC_n = Observed component variables that define the constraints militating against catfish production in the study area.; $a_1 - a_n$ = Correlation coefficients or constraint factor loading matrix; X_1, X_2, … X_n = Unobserved causal factors constraining catfish production in the study area..

3.0 Results and Discussion

3.1 Socio-economic Characteristic of Catfish Producers

The socioeconomic characteristics of catfish producers are presented in Table 1. The result indicates that catfish producers have a mean age of 47 years, while 73.81% were between 40 and 59 years, suggesting that most producers were within the economically active age bracket suitable for commercial aquaculture. Majority (73.02%) of the producers are male, reflecting the labour-intensive and capital-demanding nature of catfish production. This male predominance is consistent with that reported by Ume and Ochiaka (2016), which noted that men are more involved in catfish production than females. Married producers constituted 88.89%, while the mean household size was five persons, which provides family labour for routine production activities and may reduce reliance on hired labour. Catfish producers have a mean of 10.6 years of formal education, with 65.87% attaining secondary or tertiary education. This level of education facilitates the acquisition of technical knowledge and the adoption of improved production and sustainable environmental management practices, consistent with (Ike & Gbughemobi, 2018) The mean farming experience is 6.27 years, indicating that producers had acquired practical knowledge relevant to efficient farm management. Cooperative participation was low, as 66.67% of the producers did not belong to any cooperative society and the mean membership period is 1.65 years. This may constrain access to production credit, extension services, market information and collective input procurement. Furthermore, 92.10% of the producers engaged in off-farm activities, reflecting income diversification among producers. Although, the result also indicates that producers have a mean of nine extension contacts, 30.16% had no contact with extension agents during the production period. Limited interaction with extension services may restrict access to improved production technologies and sustainable environmental management practices capable of enhancing farm management performance.

Table 2: Distribution of Catfish Producers according to their Socio-economic Characteristics in Anambra State

Variable	Frequency	Percentage
Age		
20 – 29	4	3.17
30 – 39	17	13.49
40 – 49	48	38.1
50 – 59	45	35.71
60 – 69	12	9.52
Total	126	100
Mean	47	
Gender		
Male	92	73.02
Female	34	26.98
Total	126	100
Marital Status		
Single	11	8.73
Married	112	88.89
Widowed	2	1.59
Divorced	1	0.79
Total	126	100

Household Size		
1 – 5	81	64.29
6 – 10	45	35.71
Total	126	100
Mean	5	
Education Level		
No Formal	11	8.73
Primary	32	25.40
Secondary	56	44.44
Tertiary	27	21.43
Total	126	100
Mean	10.6	
Farming Experience		
No Prior Experience	3	2.4
1 – 5	72	57.1
6 – 10	40	31.75
11 – 15	6	4.76
16 – 20	5	4.00
Total	126	100
Mean	6.27	
Co-operative Membership		
No Membership	84	66.67
1 – 5	27	21.43
6 – 10	14	11.11
Total	126	100
Mean	1.65	

Off-farm Activities		
Yes	116	92.10
No	10	7.94
Total	126	100
Extension Contact		
No Extension Contact	38	30.16
1 – 10	46	36.51
11 – 20	31	24.60
21 – 30	10	7.94
31 – 40	0	0
41 – 50	1	0.79
Total	126	100
Mean	9	

Source: *Field Survey, 2024*

3.2 Profitability of Catfish Production

Table 3 presents the profitability of catfish production in Anambra State. The result indicates that the total cost of production (₦295,712.54/m³) exceeded the total revenue (₦261,641.16/m³), resulting in negative gross margin (₦−32,126.66/m³) and net farm income (₦−34,071.38/m³). The return on investment was estimated at −0.115, indicating that producers incurred a loss of 11.5 kobo on every ₦1.00 invested in catfish production. These indicators suggest that catfish production was not economically viable during the production period despite the substantial investment committed to the enterprise. Feed accounted for 92% of the total production cost, indicating that profitability was majorly influenced by feed expenditure. This cost structure suggests that improvements in feed utilization, feed conversion efficiency and access to lower-cost feed sources are essential for reducing production costs and improving catfish enterprise. This finding further indicates that persistent increases in production costs may discourage producers from investing in sustainable environmental management prsactices that require additional financial commitment. This observation is consistent with Chiekezie *et al*. (2023) and Ekunwe and Egware (2015), who reported that feed constituted the largest component of production cost and was the principal factor limiting profitability among catfish producers.

Table 3: Profitability of Catfish Production in Anambra State

Items	Quantity	Unit Price (N)	Value (N)/Cubic Metre	Standard Deviation	Percentage of Total Cost
Catfish Output (per kg of live weight)	3277.93	3500	261641.16	6139.78	-
Total Revenue			**261641.16**	21489236.18	-
Fingerlings (kg)	24.25	8208.75	4539.44	39.99	0.015
Feed (kg)	4979.35	2392.30	271645.67	11909.74	0.92
Water (Litres)	161103.17	1.43	5253.76	100916.51	0.012
Fertilizer (kg)	30.74	19.96	14.00	72.63	0.000
Labour (Man-days)					
Feeding	225	2242.86	11508.40	64.42	-
Fertilizing	1	2242.86	51.15	0.23	-
Sorting	2	2242.86	102.30	0.86	-
Medication	1	2242.86	51.15	0	-
Harvesting	3	2242.86	153.45	1.5	-
Total Cost of Labour	-	-	11866.45	185381.35	0.04
Transportation	-	-	448.50	23980.33	-
Total Variable Cost			**293767.82**	42771603.56	0.993
Depreciation Value of Materials/Equipment					
Pond (cubic metre)	43.85	35672.94	1035.59	62771.62	-
Harvesting Net	-	-	24.31	1577.55	-
Boreholes	-	-	194.47	12220.4	-
Pumping Machine	-	-	72.91	5776.35	-

Weighing Scale	-	-	90.23	6209.39	-
Shovel	-	-	20.29	1478.91	-
Matchet	-	-	24.31	1527.55	-
Wheelbarrow	-	-	38.89	2444.08	-
Basin/Bucket	-	-	31.12	1955.26	-
Sorting Filter	-	-	30.92	1943.04	-
Pond Net Cover	-	-	17.66	1336.94	-
Generator	-	-	364.01	24840.04	-
Total Fixed Cost			**1944.71**	122203.99	0.007
Total Cost			**295712.54**	42840604.5	-
Gross Margin			**-32126.36**	25072337.46	-
Net Income			**-34071.38**	25127365.36	-
Return on Investment			**-0.115**	-	-

Source: *Field Survey, 2024*

3.3 *Determinants of the Cost Efficiency of Catfish Producers in Anambra State*

The Stochastic Frontier Cost Function (SFCF) estimates for catfish producers in Anambra State are presented in Table 4. The Maximum Likelihood Estimation (MLE) model Is preferred because it produced a higher log-likelihood value (−30.633) than the Ordinary Least Squares (OLS) specification (−60.829). The likelihood ratio statistic (60.391; $p < 0.01$) rejected the null hypothesis of no cost inefficiency, indicating that the stochastic frontier model provided a better representation of the cost structure than the conventional regression model. The estimated sigma-squared ($\sigma^2 = 0.360$; $p < 0.01$) confirms the presence of inefficiency effects among producers, while the gamma estimate ($\gamma = 0.903$; $p < 0.01$) indicates that 90.3% of the variation in production cost was attributable to differences in cost inefficiency, with only 9.7% arising from random factors beyond producers' control. These diagnostic statistics confirm the suitability of the stochastic frontier approach for estimating cost efficiency among catfish producers in Anambra State.

The estimated cost frontier indicates that catfish output, price of fingerlings, price of feed and price of labour significantly influenced production cost. Catfish output exhibited a positive elasticity (0.748; $p < 0.01$), indicating that increases in output were associated with higher production costs. Since the elasticity is less than one, production costs increased at a slower rate than output, suggesting the existence of economies of scale. This implies that producers operating at larger output levels were able to distribute part of their fixed production costs over a larger volume of production, thereby reducing average production cost. Feed price also exerts a positive influence on total production cost (0.571; $p < 0.05$), confirming its importance as the principal variable cost in catfish production. Rising feed prices are transmitted directly into production costs because feed constitutes an indispensable input with limited substitutes. Similar observationss were reported by Imade and Odum (2024), and Onyeneke (2020), who found feed expenditure as the highest cost component in catfish farming. Similarly, labour price increased production cost (0.551; $p < 0.01$), reflecting the labour-intensive nature of pond preparation, feeding, water management, sorting and harvesting operations. This finding suggests that improvements in labour organization and operational efficiency would contribute to lowering production costs. Conversely, the price of fingerlings exhibits a negative relationship with production cost (−0.097; $p < 0.10$). While this result deviates from theoretical expectation, it may indicate that producers purchasing high quality fingerlings benefited from better survival, faster growth and improved feed conversion efficiency, thereby reducing the expenses associated with mortality, replacement stocking and prolonged production cycles.

The cost inefficiency model indicates that farming experience, extension contact and the SEMP Index significantly influenced cost inefficiency. Farming experience exhibits a positive relationship with cost inefficiency (0.048; $p < 0.10$), suggesting that producers with more production experience were not necessarily more cost efficient. This finding may imply continued reliance on established production practices that are less responsive to evolving technologies, input markets and cost-saving innovations. Extension contact reduces cost inefficiency (−0.047; $p < 0.10$), indicating that regular interaction with extension agents enhanced producers' access to improved information, efficient input management and better farm management practices. This finding agrees with Ashley-Dejo (2022), who reported that extension services improve farm-level efficiency through better management decisions. The SEMP Index exhibits a positive relationship with cost inefficiency (0.603; $p < 0.01$), indicating that higher environmental management performance was associated with increased production costs. This finding suggests that adopting environmentally sustainable production practices may require additional expenditure on activities such as water quality management, pond sanitation, waste treatment and environmental protection. Such investments may increase production costs during the early stages of adoption before the efficiency gains associated with improved environmental management become evident. The finding should not be interpreted as evidence that environmental sustainability reduces farm performance. Rather, it indicates that the transition towards environmentally responsible aquaculture may involve short run cost adjustments that support more sustainable production over time.

Table 4: Estimates of the Stochastic Frontier Cost Function for Catfish Producers in Anambra State

Variables	**OLS**		**MLE^{+}**	
	Coefficients	**SE**	**Coefficients**	**SE**
Constant P_0	-6.493 (-3.233)***	2.009	1.768 (0.847)	2.089
Quantity of Catfish (kg)	0.880 (20.901)***	0.042	0.748 (15.759)***	0.047
Price of Fingerlings P_1	-0.065 (-0.884)	0.073	-0.097 (-1.783)*	0.054
Price of Pond P_2	-0.003 (0.062)	0.044	-0.017 (-0.509)	0.034
Price of Feed P_3	1.536 (8.151)***	0.188	0.571 (2.313)**	0.247

Price of Water P_4	-0.028 (-0.419)	0.066	0.059 (1.251)	0.047
Price of Labour P_5	0.520 (2.900)***	0.179	0.551 (4.625)***	0.119
Price of Fertilizer P_6	-0.020 (-2.233)**	0.009	-0.005 (-0.853)	0.006
Determinants of Cost Inefficiency				
Constant Z_0	-	-	-3.182 (-2.130)**	1.494
Age Z_1	-	-	0.015 (0.961)	0.016
Level of Education Z_2	-	-	0.044 (1.503)	0.030
Farming Experience Z_3	-	-	0.048 (2.087)*	0.023
Household Size Z_4	-	-	0.090 (1.296)	0.070
Marital Status Z_5	-	-	0.555 (1.284)	0.433
Cooperative Membership Z_6	-	-	-0.029 (-0.650)	0.045
Extension Contact Z_7	-	-	-0.047 (-1.893)*	0.025
SEMP Index Z_8	-	-	0.603 (2.958)***	0.204
Diagnostic Parameters				
Sigma Squared (δ^2)	-	-	0.360 (2.807)***	0.128
Gamma (γ)	-	-	0.903 (10.811)***	0.084
Log-likelihood	-60.829	-	-30.633	-
	Statistic		**Df**	**P value**
LR Test	60.391		10	0.00***

Source: *Field Survey (2024). SE denotes Standard Errors. + denotes Lead Equation. Figures in parenthesis are Z values. *, ** and *** denote levels of significance at 10%, 5% and 1% respectively.*

3.3.1 *Cost Efficiency Indices of Catfish Producers in Anambra State*

The distribution of cost efficiency indices of catfish producers in Anambra State is presented in Table 5. The result indicates that cost efficiency ranged from 0.13 to 0.95, with a mean cost efficiency of 0.72. This suggests that producers operated at 72% of the attainable cost efficiency level, implying that production costs could still be reduced by 28% without lowering output provided the available resources are better utilized. The estimated mean cost efficiency exceeds the 0.53 reported by Islam *et al*. (2023), indicating relatively better cost management among catfish producers in the study area. The distribution further shows that 31.0% of the producers recorded cost efficiency scores between 0.80 and 0.89, while 24.6% operated within the 0.90–0.99 efficiency range. This pattern indicates that a considerable proportion of producers operated close to the cost frontier, even though efficiency differentials persisted across farms. On the contrary, only a small proportion of producers fell within the lower efficiency ranges, suggesting that cost inefficiency was concentrated among relatively few farms. It is estimated from the result that the least efficient producer would require an 86.3% reduction in production cost to attain the cost frontier, while the average producer would require a 24.2% reduction. These findings suggest that, despite the relatively high average cost efficiency, opportunities still exist for improving cost performance through efficient utilization of production resources and improved management practices.

Table 5: Distribution of Catfish Producers according to their Cost Efficiency Indices in Anambra State

Efficiency range	Frequency	Percentage
0.10 – 0.19	6	4.8
0.20 – 0.29	7	5.6
0.30– 0.39	7	3.2
0.40 – 0.49	3	2.4
0.50 – 0.59	9	7.1
0.60 – 0.69	10	7.9
0.70 – 0.79	14	13.5
0.80 – 0.89	39	31
0.90 – 0.99	31	24.6
Total	**126**	**100**
Minimum	**0.13**	
Maximum	**0.95**	
Mean	**0.72**	

Source: *Field Survey (2024).*

3,4.1 *Sustainable Environmental Management Practices used by Catfish Producers in Anambra State*

Table 6 presents the SEM practices used by catfish producers in Anambra State. The results indicate that the implementation of SEM practices varied considerably across production activities. Producers recorded high adoption of relatively simple and management-oriented practices, particularly siting ponds away from flood-prone areas (96.83%), siting ponds away from disease-sensitive areas (89.68%), frequent water replacement (88.10%), preventing fish escape from ponds (84.90%), avoiding overcrowding (84.13%) and cleaning ponds after each production cycle (80.16%). These practices are closely associated with routine pond management and disease prevention and are likely to improve fish survival, maintain water quality and reduce production losses. Their widespread adoption suggests that producers readily embraced environmental practices that also support day-to-day farm management and production efficiency.

Moderate adoption was observed for practices requiring some level of planning and investment, including increasing pond dyke heights (67.46%), proper drainage systems (64.29%), integrated aquaculture (63.49%), flow-through or recirculatory pond systems (61.90%) and pond designs that maximize natural sunlight exposure (61.11%). These practices indicate increasing awareness of environmentally responsible production, but also suggest that financial and technical considerations may influence their implementation. On the contrary, practices involving environmental monitoring, biosecurity and resource conservation recorded comparatively low adoption. Only 20.63% of producers monitored water pH and temperature, 13.49% measured dissolved oxygen, 19.84% treated wastewater before disposal, 17.46% used renewable energy sources, while only 7.94% implemented biosecurity measures. Compliance with environmental regulations was also limited (35.71%). These findings suggest that producers were more likely to adopt practices with immediate production benefits than those requiring specialized knowledge, additional investment or long-term environmental commitment. Overall, 51% of the producers recorded SEM practice scores above 50%, indicating that environmentally sustainable production practices had gained moderate acceptance among catfish producers. The relatively low adoption of several environmentally responsible practices nonetheless suggests that considerable potential exists for strengthening sustainable aquaculture through improved technical support, environmental awareness and institutional assistance.

Table 6: Sustainable Environmental Management Practices used by Catfish Producers in Anambra State

Practices	Frequency	Percentage
Procure fish seeds from registered/recognized sources	42	33.33
Implement biosecurity measures	10	7.94
Site ponds far from flood prone areas	122	96.83
Site ponds away from disease sensitive areas	113	89.68
Clean ponds after each production cycle	101	80.16
Treat waste/water before disposing	25	19.84
Avoid overcrowding of catfish	106	84.13
Responsible use of antibiotics and aqua-chemicals	25	23.02
Have strategies for reducing waste build up in the pond	27	21.43
Measure dissolved oxygen in water	17	13.49

Measure water P^H and water temperature	26	20.63
Frequently changing water in the pond	111	88.10
Have no fish escape from ponds	107	84.90
Implement integrated aquaculture	80	63.49
Increase pond dyke heights	85	67.46
Use of ponds with flow-through or re-circulatory systems	78	61.90
Use of proper pond design to maximize natural sunlight exposure	77	61.11
Proper drainage systems	81	64.29
Use of energy efficient aeration systems	49	38.89
Use of renewable energy sources such as: solar to power pumps and other equipment	22	17.46
Adherence to local and national environmental regulations	45	35.71
Producers with SEM practice score above 50%	**64**	**51**

Source: *Field Survey (2024).*

3.4.2 ***Sustainable Environmental Management Performance Indices of Catfish Producers in Anambra State***

Table 7 presents the Sustainable Environmental Management Performance (SEMP) indices of catfish producers in Anambra State. The result indicates that the SEMP index ranged from 0.27 to 0.80, with a community average of 0.56. This indicates that producers attained, on average, 56% of the expected environmental management performance, suggesting a moderate level of compliance with environmentally sustainable aquaculture practices. The estimated community average suggests that environmental considerations have become integrated into catfish production, even though the level of environmental management performance appear within average levels. The distribution of the indices shows that 40.50% of the producers recorded SEMP scores between 0.55 and 0.64, indicating that environmental management performance was concentrated around the community average. However, only 3.17% of the producers attained SEMP scores within the highest performance range (0.75–0.84), while an equal proportion fell within the lowest range (0.25–0.34), suggesting that relatively few producers operated at either extreme of environmental performance. The result also indicates that 44% of the producers recorded SEMP scores below the community average, implying that environmentally sustainable production practices had not yet been fully integrated across all catfish enterprises. This distribution suggests that considerable opportunity exists to improve environmental management performance through wider adoption of sustainable production practices, thereby strengthening the environmental sustainability of catfish production in Anambra State

Table 7: Distribution of Catfish Producers according to their Sustainable Environmental Management Performance Indices in Anambra State

$SEMP_{index}$ range	Frequency	Percentage
0.25 – 0.34	4	3.17
0.35 – 0.44	14	11.11
0.45 – 0.54	33	26.20
0.55 – 0.64	51	40.50
0.65 – 0.74	20	15.87
0.75 – 0.84	4	3.17
Total	**126**	**100**
Minimum	**0.27**	
Maximum	**0.80**	
Community Average	**0.56**	
% Below Community Average	**44**	

Source: *Field Survey (2024).*

3.5 *Determinants of the use of Sustainable Environmental Management Practices among Catfish Producers in Anambra State*

The estimates of the Probit model explaining the use of SEM practices among catfish producers in Anambra State are presented in Table 8. The likelihood ratio statistic (LR = 34.87; $p < 0.01$) indicates that the explanatory variables jointly influenced producers' decisions to use SEM practices. The McFadden pseudo-R^2 of 0.210 suggests that the model accounted for 21% of the observed variation in adoption behaviour, while the Hosmer–Lemeshow statistic ($\chi^2 = 7.70$; $p = 0.463$) indicates a satisfactory fit between the predicted and observed outcomes. These diagnostic statistics confirm the suitability of the Probit model for explaining the adoption of SEM practices among catfish producers.

The results indicate that net income, farming experience and the number of fingerlings stocked significantly influenced the probability of adopting SEM practices. Net income exerts a negative effect on the likelihood of adoption (coefficient = −0.032; marginal effect = −0.010; $p < 0.01$), indicating that an increase in net income reduced the probability of using SEM practices by 1.0%. This finding suggests that higher earnings did not necessarily translate into greater environmental investment among producers. It may reflect the tendency for additional income to be directed towards expanding production or meeting other farm obligations rather than implementing environmental management measures that are perceived to yield benefits over a longer period. This finding contradicts the observation of Aung *et al*. (2021), who reported that the adoption of sustainable aquaculture technologies improved the welfare of fish farmers.

Farming experience exerts a positive influence on the use of SEM practices (coefficient = 0.348; marginal effect = 0.107; $p < 0.10$), implying that an additional year of farming experience increased the probability of adoption by 10.7%. This finding suggests that producers who had spent more years in aquaculture were better positioned to appreciate the production and environmental consequences of poor pond management and were consequently more inclined to adopt environmentally sustainable production practices. Similarly, the number of fingerlings stocked exhibits a positive and significant relationship with SEM practice adoption (coefficient = 0.605; marginal effect = 0.187; $p < 0.01$). The marginal effect indicates that increasing the scale of stocking raised the probability of adopting SEM practices by 18.7%. This finding suggests that producers operating at relatively larger production scales had stronger incentives to maintain favourable pond conditions because environmental deterioration could result in greater biological and economic losses. Maintaining good water quality, reducing disease incidence and minimizing mortality become increasingly important as stocking intensity increases. This finding is consistent with Lowanshi *et al*. (2024), who observed that higher stocking densities increase waste accumulation, deteriorate water quality and heighten the risk of disease outbreaks in aquaculture systems

Table 4.31: Estimates of Probit Regressions of Factors Influencing the use of Sustainable Environmental Management Practices among Catfish Producers in Anambra State

Variables	**Probit Regression**		**Marginal Effects**	
	Coefficients	**SE**	**Coefficients**	**SE**
Constant X_0	0.889 (0.328)	2.709	-	-
Net Income X_1	-0.032 (-3.344)***	0.010	-0.010 (-3.117)***	0.003
Age X_2	-0.0673 (-0.865)	0.779	-0.208 (-0.876)	0.237
Years Spent in School X_3	-0.097 (-0.614)	0.158	-0.030 (-0.611)	0.049
Farming Experience X_4	0.348 (1.777)*	0.196	0.107 (1.705)*	0.063
Household Size X_5	0.464 (1.563)	0.297	0.144 (1.472)	0.097
Gender X_6	-0.357 (-1.096)	0.326	-0.110 (-1.121)	0.098
Production Cycle per Year X_7	-0.122 (-0.451)	0.271	-0.040 (-0.450)	0.084
Fingerlings Stocked X_8	0.605 (3.616)***	0.167	0.187 (3.500)***	0.053
Extension Contact X_9	-0.023 (-0.183)	0.124	-0.007 (-0.168)	0.042
Diagnostic Parameters				
McFadden Pseudo-R^2	0.210	-	-	-

Log-likelihood	-65.73	-	-	-
	Statistic		**Df**	**P values**
LR Test	34.87		9	0.00
Hosmer-Lemeshow Test	7.70		8	0.463

Source: *Field Survey (2024). SE denotes Standard Errors. Figures in parenthesis are Z values. *, ** and *** denote levels of significance at 10%, 5% and 1% respectively.*

3.6 *Constraints to Catfish Production in Anambra State*

Figure 2 presents the rotated factor components for the major constraints affecting catfish production in Anambra State. The Kaiser-Meyer-Olkin (KMO) value of 0.853 and the significant Bartlett's Test of Sphericity ($\chi^2 = 5225.34$; $p < 0.001$) indicate that the data were suitable for factor analysis. The six extracted factors jointly explained 59.94% of the total variation in the observed constraints, suggesting that they adequately captured the major challenges affecting catfish production in the study area. The first factor represents input and production constraints, characterized principally by high production costs, inadequate extension services, poor water quality, inadequate post-harvest technologies and limited adoption of modern production technologies. These constraints increase production costs and reduce farm productivity. Similar constraints involving high input costs, inadequate extension services, poor water quality and limited access to modern technologies have been reported among fish producers in Nigeria (Ifeonu *et al*., 2019). The second factor reflects operational and technical constraints, comprising scarcity of skilled labour, high fish mortality, inadequate technical support, scarcity of quality fingerlings and weak government and veterinary support services, all of which affect efficient farm management. The third factor captures institutional and financial constraints, with high interest rates, inadequate access to affordable credit, insufficient financial support and poor economic conditions constituting the major impediments to the expansion of and investment in catfish enterprise. Similar financial and credit constraints have been reported among fish producers (Abeguntin *et al*., 2019; Ume *et al*., 2018; Ume & Ochiaka, 2018). The fourth factor describes environmental constraints, driven mainly by the frequent occurrence of natural calamities, pests and diseases, predators and high temperature, indicating that environmental shocks continue to threaten production performance (Ifeonu *et al*., 2019; Ume & Ochiaka, 2018). The fifth factor represents marketing constraints, including inadequate marketing channels, low farm-gate prices, weak market organization and poor bargaining power, which reduce producers' returns despite rising production costs. The sixth factor comprises infrastructural constraints, characterized by inadequate electricity supply, poor road networks, transportation challenges and high land rental costs, reflecting deficiencies in rural infrastructure that increase transaction costs and constrain efficient aquaculture production (Wasiru, 2016). These findings suggest that improving catfish production in Anambra State requires coordinated interventions that address production, institutional, environmental, marketing and infrastructural bottlenecks simultaneously rather than through isolated policy actions.

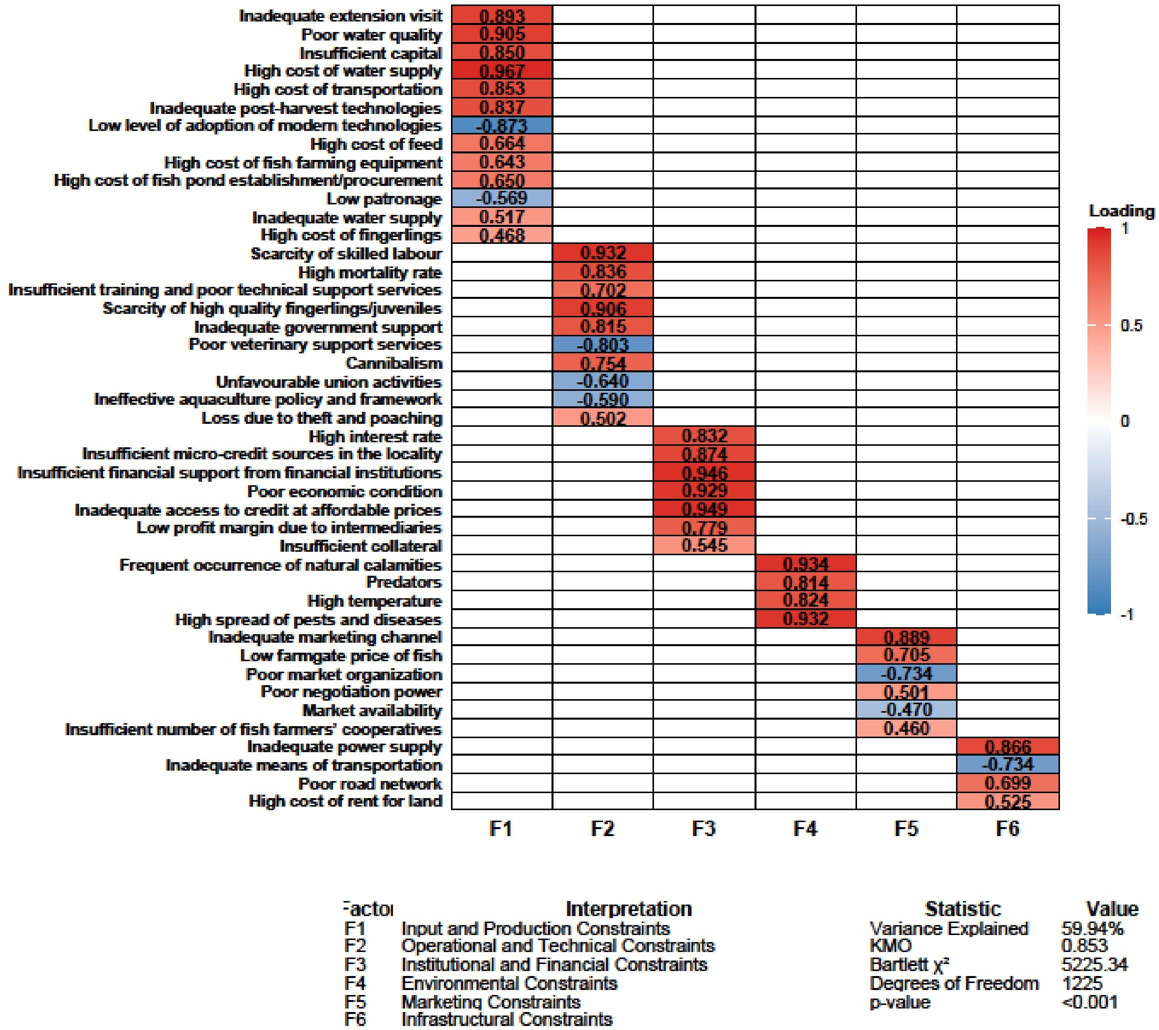


Figure 2 Rotated factor Components of the Major Constraints affecting Catfish Production in Anambra State.

4.0 Conclusion

This study demonstrates that improving the sustainability of catfish production in Anambra State extends beyond increasing production and requires simultaneous attention to cost efficiency and environmental stewardship. Although, producers have made measurable progress in implementing SEM practices, the associated compliance costs and persistent production constraints continue to limit cost efficiency and profitability. The findings further suggest that environmentally sustainable aquaculture and farm-level cost efficiency are not mutually exclusive; rather, the benefits of SEM are likely to be realized when producers operate within an enabling production environment that ensures efficient input markets, institutional support and appropriate production technologies. Thus, achieving a more competitive and environmentally responsible catfish industry depends on policies that balance short term production costs with long term sustainability objectives.

5.0 Recommendation

i. Efforts should prioritize improving producers' access to quality feed and fingerlings through support for local input production and efficient distribution systems to reduce dependence on expensive external supplies.

ii. Agricultural extension services should be strengthened to provide regular technical guidance on cost-saving production practices alongside practical training on water quality management, biosecurity and waste treatment.

iii. Access to affordable credit should be expanded through dedicated aquaculture financing schemes with simplified lending conditions to enable producers to invest in improved technologies and environmental management facilities.

iv. State and local governments should increase investment in rural infrastructure, particularly electricity, road networks and transportation systems, to reduce transaction costs and improve market access. Targeted incentives, including grants, input subsidies, tax relief or environmental stewardship support can also help offset the short-run costs associated with adopting environmentally sustainable practices.

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