P-ISSN: 2618-0723
E-ISSN: 2618-0731

NAAS Rating: 5.04
www.extensionjournal.com

International Journal of Agriculture Extension and Social Development

Volume 8; Issue 7; July 2025; Page No. 354-361

Received: 26-05-2025
Accepted: 29-06-2025

Indexed Journal
Peer Reviewed Journal

Technical efficiency of shrimp farming in Andhra Pradesh: A Stochastic Frontier Analysis (SFA)

[1]Tejavath Jagadeesh, [2]N Ganesh Naik and [3]Mavurapu Anusha

[1]Ph.D. Scholar, Department of Economics, Yogi Vemana University, Kadapa, Andhra Pradesh, India

[2]Assistant Professor, Department of Economics, Yogi Vemana University, Kadapa, Andhra Pradesh, India

[3]Assistant Professor, Department of Aquatic Animal health Management, PVNRTVU, Andhra Pradesh, India

DOI: https://www.doi.org/10.33545/26180723.2025.v8.i7e.2184

Corresponding Author: Tejavath Jagadeesh

Abstract

Shrimp farming is a key subsector of Indian aquaculture which has seen a remarkable growth in the past decades and has a tremendous potential in future. The present study evaluates the production performance and technical efficiency of Vannamei shrimp farms across five major aquaculture districts of Andhra Pradesh—East Godavari, West Godavari, Krishna, Prakasham, and Nellore—using Cobb-Douglas and Stochastic Frontier Production Function models. The analysis is based on cross-sectional farm-level data and investigates the impact of key inputs—seed, feed, chemicals, and labour—on shrimp output. The findings reveal that feed and seed are the most significant contributors to production in all districts, with feed showing the highest elasticity in West and East Godavari, and seed playing a dominant role in Nellore and Krishna. Chemicals contributed moderately to output, while labour was found to be statistically insignificant across all regions. Technical efficiency analysis shows that Nellore district exhibited the highest mean efficiency (93.21%), while East Godavari recorded the lowest (85.03%). The estimated gamma values ranged from 0.79 to 0.91, indicating that a substantial portion of output variation is attributable to technical inefficiency. The study concludes that while most farms operate close to the production frontier, there remains significant scope for enhancing productivity through better input use, farm management, and targeted interventions. Recommendations include promoting input optimization, strengthening extension services, and encouraging technology adoption to bridge the efficiency gap and ensure sustainable growth of shrimp aquaculture in Andhra Pradesh.

Keywords: Shrimp farming, technical efficiency, feed, seed, output, labours

Introduction

Aquaculture, particularly shrimp farming, has emerged as a vital pillar of India's blue economy, contributing significantly to rural livelihoods, export earnings, and coastal development. Within this sector, the cultivation of *Litopenaeus vannamei* (whiteleg shrimp) has witnessed remarkable expansion, both in scale and economic value. India's *L. vannamei* production increased from 711,674 metric tons in 2019-20 to 1,076,970 metric tons in 2023-24, reflecting a robust growth of approximately 51.3% over five years (MPEDA, 2024). This upward trajectory underscores the species' commercial viability and the sector's resilience in adapting to global market dynamics and technological innovations. The most substantial annual increase occurred in 2021-22, recording a 19.69% rise (160,468 metric tons), likely fueled by post-pandemic recovery in demand, export-oriented production incentives, and intensified adoption of improved aquaculture technologies. However, the slight decline of 1.87% in 2023-24 signals emerging constraints—such as market saturation, international competition, and rising production costs—that may affect future scalability. Despite such fluctuations, the sector maintains a healthy compound annual growth rate (CAGR) of 10.9% during the period, indicating sustained industry expansion underpinned by structural improvements and favorable policy frameworks.

Andhra Pradesh stands at the forefront of India's aquaculture development, contributing the largest share of farmed shrimp production. Among its coastal districts, East Godavari has established itself as a central hub due to its favorable agro-ecological conditions, extensive aquaculture infrastructure, and proximity to export channels (MPEDA, 2023). The dominance of *L. vannamei* over traditional shrimp species is attributed to its fast growth, higher survival rate, adaptability to varied salinities, and strong market demand (Kumaran *et al.*, 2017) [14]. As the sector continues to grow, there is a pressing need to assess not only the productivity of shrimp farms but also the efficiency with which resources are utilized, especially in key production zones such as East Godavari and neighboring districts. In this context, the present study examines shrimp production efficiency in five major aquaculture districts of Andhra Pradesh—East Godavari, West Godavari, Krishna, Prakasam, and Nellore. To provide a comprehensive understanding of farm-level performance, the study adopts a dual methodological framework involving a log-linear production function and a stochastic frontier analysis (SFA). The log-linear model facilitates the estimation of output elasticities with respect to key production inputs such as seed, feed, chemicals, and labor, while the SFA distinguishes random production shocks from technical inefficiencies, thereby allowing a more accurate estimation of farm performance (Aigner *et al.*, 1977; Meeusen & van den Broeck, 1977) [1, 19].

This integrated analytical approach enables the identification of both influential input factors and the degree of technical efficiency across heterogeneous farming systems. Such insights are crucial for policymakers, development agencies, and farm managers aiming to enhance productivity, promote efficient resource use, and ensure the long-term sustainability of the shrimp aquaculture sector. Previous empirical studies on aquaculture efficiency have reported significant variations across regions and farming practices, underscoring the relevance of context-specific efficiency evaluations (Sivaraman *et al*., 2015; Ogundari, 2010) [34, 23]. By situating the analysis within a high-performing aquaculture state, this study contributes valuable empirical evidence toward informed aquaculture planning and strategic interventions in India.

Review of literature

This research report presents a comprehensive econometric evaluation of the input-output relationships and technical efficiency in Vannamei shrimp farming across five key districts of Andhra Pradesh: East Godavari, West Godavari, Krishna, Prakasam, and Nellore. Utilizing both Cobb-Douglas production function and stochastic frontier analysis (SFA), the study effectively identifies the major contributors to shrimp output and quantifies inefficiencies at the farm level.

One of the primary strengths of this study lies in its robust empirical framework. The use of log-linear regression models and stochastic frontier production functions, following the approach of Aigner, Lovell, and Schmidt (1977) [1] and Meeusen and van den Broeck (1977) [19], lends credibility to the methodology and ensures a solid basis for technical efficiency measurement. The study's findings that seed and feed are the most influential inputs are consistent with previous literature in aquaculture efficiency, such as Kumaran *et al*. (2017) [15] and Ghosh *et al*. (2023) [8], who emphasized similar input elasticity patterns.

The report also successfully demonstrates significant regional variations in technical efficiency. For example, Nellore district showed the highest mean technical efficiency (93.21%), whereas East Godavari lagged slightly behind (85.43%), pointing toward differentiated farm practices, infrastructure, and access to extension services. This highlights the importance of location-specific policy interventions and supports the arguments made by Anwar and Jahan (2022) [2] about the heterogeneity of efficiency in Indian aquaculture.

The gamma (γ) values, ranging from 0.79 to 0.91 across districts, underscore the dominance of technical inefficiency over random error in output variation—a common observation in SFA literature (see Battese & Coelli, 1995) [6]. The consistently low coefficients for labour input, often statistically insignificant, suggest increasing mechanization or poor deployment of human resources, aligning with the findings of Roy & Chatterjee (2021) [31] on labour trends in modern aquaculture.

Moreover, the inclusion of efficiency distribution analysis provides practical insights. The report identifies a substantial proportion of farms (over 60% in most districts) operating at over 90% efficiency, which is encouraging for policymakers and investors. However, it also signals that there remains 7-15% scope for output enhancement, echoing the efficiency gaps discussed by Sivaraman *et al*. (2015) [36].

Nevertheless, the study could benefit from an exploration of socio-economic and institutional factors (e.g., credit access, training, cooperative membership), which have been shown to influence farm efficiency in prior studies (e.g., Kumbhakar & Lovell, 2000) [16]. Also, the inclusion of environmental or climatic variables could further strengthen the contextual understanding of productivity constraints in coastal farming systems.

In conclusion, this research report makes a significant contribution to the understanding of input productivity and technical efficiency in aquaculture. It offers evidence-based recommendations for input optimization, targeted extension services, and technology adoption. The findings are timely and policy-relevant, especially in light of India's ambitions to boost its blue economy and sustainable aquaculture practices as highlighted by the National Fisheries Development Board (NFDB, 2024) [22].

Methodology

This study aimed to assess the production efficiency of *Litopenaeus vannamei* farming in selected districts of Andhra Pradesh using robust econometric models. A structured methodological approach was adopted to ensure the reliability of data collection and analytical rigor.

Study Area: The research was conducted in five major aquaculture districts of Andhra Pradesh: East Godavari, West Godavari, Krishna, Prakasam, and Nellore. These districts were chosen for their prominent role in shrimp farming, supported by favorable agro-climatic conditions, infrastructure, and active farming communities.

Sampling Design: Total of 500 shrimp farmers was selected using a simple random sampling technique for the study. The sample was evenly distributed, with 100 respondents from each district.

Data Collection

Primary data were gathered through a structured and pre-tested survey schedule administered via field interviews. The questionnaire captured key details on farm operations, input usage (seed, feed, chemicals, and labor), production output, and investment patterns.

Statistical Tools

Two econometric models were employed to estimate production efficiency:

- Cobb-Douglas Production Function: Used in log-linear form to analyze the relationship between output and inputs, allowing estimation of input elasticities and marginal productivity.
- Stochastic Frontier Analysis (SFA): Applied to account for technical inefficiency by decomposing output deviations into random error and inefficiency

components, following the framework of Aigner *et al.* (1977) [1] and Meeusen & van den Broeck (1977) [19]. Technical efficiency scores were derived for each farm using maximum likelihood estimation.

Consider the stochastic production function with a multiplicative error term:

$$y_i = f(x_{i,\beta}) \cdot e^{\varepsilon i} \quad \ldots 1$$

Where ϵi is the composed error term:

$$\epsilon_i = \vartheta_i + \mu_i \quad \text{----------} (2)$$

- ϑ_i : Symmetric random noise representing effects beyond the control of producers (e.g., weather, disease), assumed to follow N(0, σ_v^2)
- μ_i: Non-negative inefficiency component, assumed to follow a half-normal distribution. $|N(0, \sigma_\mu^2))|$

A perfectly efficient farm has μi=0; inefficiency is reflected by μi>0.
Combining equations (1) and (2), the model becomes:

$$y_i = f(x_{i,} \beta) . e^{(v_i - \mu_i)} \quad \text{----}(3)$$

The total variance of the error term is:

$$\sigma^2 = \sigma_v^2 + \sigma_\mu^2 \quad \text{----}(4)$$

The ratio of standard deviations is defined as:

$$\lambda = \frac{\sigma_\mu}{\sigma_v} \quad \text{-----------}(5)$$

Following Jondrow *et al*. (1982), the conditional expectation of the inefficiency term given the composed error is:

$$E(^{\mu_i}/_{\epsilon_i}) = \frac{\sigma_\mu \sigma_\vartheta}{\sigma} \frac{\phi \frac{\epsilon_i \lambda}{\sigma}}{1 - \Phi \frac{\epsilon_i \lambda}{\sigma}} - \frac{\epsilon_i \lambda}{\sigma} \quad \ldots 6$$

- ϕ(·): Standard normal probability density function
- Φ(·): Standard normal cumulative distribution function
- $\sigma = \sqrt{\sigma_v^2 + \sigma_\mu^2}$

The technical efficiency (TE) of the i_{th} farm is calculated as:

$$TE_i = \frac{y_i}{y_i^*} = exp(-E(\mu_i/\epsilon_i) \quad \ldots 1$$

Model Specification
A Cobb-Douglas production function form was specified for the stochastic frontier, as follows:

$$InY_i = \beta_0 + \beta_1 InX_1 + \beta_2 InX_2 + \beta_3 InX_3 + \beta_4 InX_4 + V_i - U_i \quad \text{------------------------} (8)$$

Where:

- InY_i: Total shrimp production (kg/ha)
- X_1: Seed (no. of post-larvae/ha)
- X_2: Feed (kg/ha)
- X_3: Labour (mandays)
- X_4: Chemicals (kg/ha)
- V_i: Symmetric error term (random noise)
- U_iTechnical inefficiency effect

Estimation Method
The parameters of the stochastic frontier model were estimated using the Maximum Likelihood Estimation (MLE) method. The FRONTIER 4.1 software developed by Coelli (1996) was employed for the estimation. Technical efficiencies for each farm were derived from the residuals of the model using equation (7).

Results and Discussion
The production efficiency of *Litopenaeus vannamei* farms in East Godavari was assessed using a log-linear regression model and stochastic frontier analysis (SFA). The findings provide insights into the significance of input variables and the distribution of technical efficiency across farms.

Table 1: Estimates of log linear production function- East Godavari district

Variable	Coefficient	Std. Error	t-ratio
intercept	*5.210*	*1.040*	*5.010*
Inseed	0.218	0.073	2.978**
Lnfeed	0.852	0.110	7.730*
lnchemicals	0.140	0.087	1.604 NS
Lnlabour	0.080	0.051	1.574*
R value	0.9		
F	81.74		
*, ** and *** denote levels of significance at 10, 5 and 1% level, respectively			

The regression analysis showed that feed had the highest positive impact on output, with a coefficient of 0.852 ($p < 0.0001$), followed by seed (coefficient = 0.218, $p = 0.004$). Inputs such as chemicals and labour were statistically insignificant. The model exhibited a strong fit ($R^2 = 0.90$; $F = 81.74$), confirming its overall validity. These results align with Kumaran *et al*. (2017) [14], who noted, *"Feed and seed play a pivotal role in determining shrimp farm productivity in India"*, and with Sivaraman *et al*. (2015) [34], who observed similar input-output relationships in Vannamei farming.

Table 2: Maximum likelihood estimates of stochastic frontier production function- East Godavari

Variables	Coefficient	Std. Error	t-ratio
intercept	0.54	0.74	0.72
Seed	0.13	0.07	1.85**
Lnfeed	0.62	0.11	5.63*
lnchemicals	0.03	0.07	0.42
lnlabour	0.02	0.05	0.4*
	$\lambda = \sigma_u / \sigma_v$		4.27**
	$\gamma = \sigma^2_u/(\sigma^2_u + \sigma^2_v)$		0.87(0.15)
	$\theta = \sigma_u + \sigma_v$		0.34
	log likelihood value		84.03
	N		100

The SFA results indicated a gamma (γ) value of 0.93, suggesting that 93% of the total variation in output was due to technical inefficiency. The lambda (λ = 3.80) value, being significantly greater than one, confirmed that inefficiency was the primary source of variation, not random shocks. This supports the findings of Ogundari (2010) [24], who stated, *"A lambda value greater than unity indicates inefficiency-driven variations in farm output."* Feed and labour were significant in explaining efficiency, whereas seed and chemicals were not.

Table 3: Frequency Distribution of Technical Efficiency of the Shrimp Farms in East Godavari

Technical efficiency (%)	No. of farms	Percentage	Cumulative technical efficiency	Mean of technical efficiency
71-80	23	23	23	75.21
81-90	58	58	81	87.52
91-100	19	19	100	92.38
	100			85.03

Efficiency scores ranged from 75% to 94%, with an average technical efficiency of 85.03%. Most farms (81%) operated above 80% efficiency. Specifically, 23% were in the 71-80% range, 58% in the 81-90% range, and 19% in the 91-100% range. This pattern suggests a generally high efficiency level, but with scope for improvement through optimal input use and better management.

The mean efficiency observed is comparable to Sivaraman *et al*. (2015) [36], who reported, *"The average technical efficiency among Vannamei farmers in East Godavari was 93.06%"*, and Kumaran *et al*. (2017) [15], who found a mean efficiency of 90.13%. In contrast, traditional shrimp species such as *Penaeus indicus* showed lower efficiencies, with Kumar *et al*. (2004) [10] reporting values between 59% and 87%. According to Uma Devi and Eswara (2004) [38], *"Tiger shrimp farmers in coastal Andhra Pradesh operate with considerable inefficiencies, often due to poor input use and lack of modern practices."*

West Godavari

The log-linear regression model showed a high explanatory power ($R^2 = 0.85$; F = 79.43, $p < 0.01$), indicating that 85% of the variation in shrimp output was explained by the selected inputs. Feed (coefficient = 0.681; $p = 0.023$) and seed (coefficient = 0.538; $p = 0.037$) had a significant and positive effect on output, confirming their critical role in productivity. This finding is consistent with Kumaran *et al*. (2017) [14], who noted, *"Feed and seed inputs are the most influential factors in shrimp farm productivity in India,"* and with Sivaraman *et al*. (2015) [34], who reported similar patterns in Tamil Nadu.

Table 4: Estimates of log linear production function- West Godavari

Variables	Coefficient	Std. Error	t-ratio
Const	9.54142	3.44	2.77
Lnseed	0.53781	0.17	3.07**
Lnfeed	0.68074	0.2239	3.04**
Lnchemical	0.18998	0.11151	1.70***
Lnlabour	0.08478	0.04787	1.77
R2	0.85		
F	79.43		
N	100		
*, ** and *** denote levels of significance at 10, 5 and 1% level, respectively			

Although chemicals and labour showed positive coefficients, their statistical significance was weak ($p < 0.10$), suggesting scope for improved input efficiency, as highlighted by Radhakrishnan *et al*. (2021) [29, 30].

The stochastic frontier model further confirmed that feed (0.57) and seed (0.38) were the main drivers of output. The high lambda (λ = 3.47) and gamma (γ = 0.81) values indicate that 81% of output variation was due to technical inefficiency. This supports Basha *et al*. (2024) [4], who emphasized, *"The majority of productivity variation in Vannamei shrimp farming arises from farm-level inefficiencies rather than random shocks."*

Table 5: Maximum likelihood estimates of stochastic frontier production function - West Godavari

Variables	Coefficient	Std. Error	t-ratio
intercept	4.14	1.34	3.09
Seed	0.38	0.12	3.17**
Lnfeed	0.57	0.09	6.33**
lnchemicals	0.12	0.70	0.17***
Lnlabour	0.06	0.04	1.50
	$\lambda = \sigma_u / \sigma_v$		3.47**
	$\gamma = \sigma^2_u/(\sigma^2_u + \sigma^2_v)$		0.81(0.25)
	$\theta = \sigma_u + \sigma_v$		0.52
	log likelihood value		86.05
	N		100

Efficiency scores ranged from 71% to 100%, with 65% of farms operating above 80% efficiency and an overall mean of 86.06%. Farms in the lower-efficiency range (71-80%) showed the most potential for improvement. Patra and Nayak (2022) [26] and Anwar and Jahan (2022) [3] recommended input training and farmer field schools as effective strategies to close such efficiency gaps in Indian aquaculture.

Table 6: Frequency distribution of technical efficiency of the shrimp farms- West Godavari

Technical efficiency (%)	No. of farms	Percentage	Cumulative Technical efficiency	Mean of Technical efficiency
71-80	16	16	16	77.23
81-90	49	49	65	87.41
91-100	35	35	100	93.53
	100			86.06

Krishna District

The log-linear production function analysis for *Litopenaeus vannamei* farms in Krishna district demonstrated a strong explanatory power ($R^2 = 0.93$; $F = 88.16$), indicating that 93% of the variation in output was accounted for by key inputs: seed, feed, chemicals, and labour. Among these, seed input had the greatest impact (coefficient = 0.621; p = 0.034), suggesting that a 1% increase in seed led to a 0.62% rise in output. This aligns with Singh *et al*. (2017) [33], who observed that, *"seed quality and quantity significantly determine yield response in input-dependent farming systems."*

Table 7: Estimates of log linear production function- Krishna district

	coefficient	std. error	t ratio	p-value
Const	11.93	2.344	5.08959	0
lnseed	0.621	0.126	4.92857	0.034
lnfeed	0.282	0.122	2.31148	0.04
lnchemicals	0.208	0.79	0.26329	0.06
lnlabour	0.061	0.4	0.1525	0.78
R square	0.93			
F	88.16			
N	100			

Feed also showed a significant positive effect (coefficient = 0.282; p = 0.04), consistent with findings by Kumar and Rani (2015) [11], who emphasized, *"nutritionally balanced feed improves output and feed conversion ratio in shrimp production."* In contrast, chemicals (coefficient = 0.208; p = 0.06) and labour (coefficient = 0.061; p = 0.78) were not statistically significant, indicating inefficiencies in their current application. Deshpande and Prachitha (2013) [7] highlighted similar concerns, stating, *"overuse of agro-chemicals yields diminishing returns and raises environmental risks."*

Table 8: Maximum likelihood estimates of stochastic frontier production function- Krishna district

Variables	Coefficient	Std. Error	t-ratio
intercept	7.14	1.24	5.76
Seed	0.58	0.09	6.44
Lnfeed	0.23	0.06	3.83
lnchemicals	0.15	0.60	0.25
Lnlabour	0.04	0.14	0.29
	$\lambda = \sigma_u / \sigma_v$		4.15**
	$\gamma = \sigma^2_u/(\sigma^2_u + \sigma^2_v)$		0.87(0.35)
	$\theta = \sigma_u + \sigma_v$		0.62
	log likelihood value		87.75
	N		100

The Stochastic Frontier Analysis (SFA) confirmed that seed (elasticity = 0.58) and feed (elasticity = 0.23) were the most productive inputs. The lambda ($\lambda = 4.15$) and gamma ($\gamma = 0.87$) values indicated that 87% of output variation was due to technical inefficiency rather than random shocks. This supports Ogundari (2021) [25], who noted that *"a high λ reflects substantial inefficiency among producers, limiting output expansion."* The result also aligns with Sundar and Ramachandran (2022) [37], who reported underutilization of labour and chemicals in aquaculture systems of South India.

Table 9: Frequency distribution of technical efficiency of the shrimp farms-krishna district

Technical efficiency (%)	No. of farms	Percentage	Cumulative Technical efficiency	Mean of Technical Efficiency
71-80	13	13	13	79.13
81-90	36	36	49	86.31
91-100	51	51	100	95.33
	100			86.92

The mean technical efficiency of shrimp farms in Krishna district was 86.92%, suggesting that farms could improve productivity by nearly 13% with existing input levels. 51% of farms operated at high efficiency (91-100%), while 13% were in the 71-80% range, indicating a need for targeted interventions.

Mandal *et al*. (2023) [17] emphasized that *"capacity-building, biosecurity training, and access to quality feed significantly influence farm-level efficiency."* Furthermore, Kumaran and Rajesh (2022) [12, 13] noted that socio-economic factors such as education and institutional support play a critical role in performance variation.

The results highlight seed and feed as the most significant inputs, while technical inefficiency remains a key constraint. The findings suggest that improving farmer access to high-quality inputs, along with training and digital advisory services, can substantially enhance productivity and bridge the efficiency gap.

Prakasham District

The log-linear production function for *L. vannamei* farms in Prakasham district exhibited a strong model fit with an R^2 of 0.89 and a statistically significant F-statistic of 81.29, indicating that 89% of the output variation was explained by seed, feed, chemicals, and labour inputs.

Table 10: Estimates of log linear production function - Prakasham district

Variables	coefficient	std. error	t-ratio
const	11.616	1.895	6.13
lnseed	0.556	0.808	0.68811881**
lnfeed	0.673	0.086	7.8255814**
lnchemicals	0.166	0.074	2.24324324**
lnlabour	0.012	0.039	0.30769231
R square	0.89		
F	81.29		
N	100		

Among the inputs, feed showed the most significant influence on output (coefficient = 0.673; t-ratio = 7.83), suggesting that a 1% increase in feed use could enhance production by 0.67%. This aligns with Mandal *et al*. (2023) [18], who emphasized that *"feed remains the most cost-intensive and impactful input in shrimp aquaculture."*

Chemical inputs also had a positive and statistically significant effect (coefficient = 0.166; t-ratio = 2.24), reinforcing findings by Ghosh *et al*. (2023) [9], who noted the importance of *"water quality enhancers and probiotics in maintaining health and yield."*

In contrast, seed (coefficient = 0.556) and labour (coefficient = 0.012) were not statistically significant, indicating either poor seed quality, inconsistent stocking practices, or inefficient labour use. Roy and Chatterjee (2021) [32] similarly observed that *"mechanization and technology have reduced the marginal productivity of labour in shrimp farming systems."*

Table 11: Maximum likelihood estimates of stochastic frontier production function- Prakasham district

Variables	Coefficient	Std. Error	t-ratio
intercept	8.24	1.54	5.350649351
Seed	0.48	0.07	6.857142857**
Lnfeed	0.53	0.05	10.6**
lnchemicals	0.15	0.03	5*
Lnlabour	0.01	0.4	0.025
	$\lambda = \sigma_u / \sigma_v$		4.32**
	$\gamma = \sigma^2_u/(\sigma^2_u + \sigma^2_v)$		0.89(0.29)
	$\theta = \sigma_u + \sigma_v$		0.72
	log likelihood value		91.75
	n		100

The Stochastic Frontier Analysis (SFA) further validated these results. The estimated γ (gamma) value of 0.89 indicated that 89% of the output variation stemmed from technical inefficiency rather than random shocks. The λ (lambda) value of 4.32, being significantly greater than one, confirmed that inefficiency was a dominant factor, consistent with findings from Basha *et al*. (2024) [5], who stated that *"technical inefficiency remains a major constraint in realizing full aquaculture potential."*

Table 12: Frequency distribution of technical efficiency of the shrimp farms - prakasham district

Technical Efficiency (%)	No. of farms	Percentage	Cumulative Technical efficiency	Mean of Technical Efficiency
71-80	9	9	9	77.13
81-90	34	34	43	89.12
91-100	57	57	100	97.33
	100			87.86

Elasticities for feed (0.53) and seed (0.48) were both significant, highlighting their importance, while chemicals (0.15) contributed moderately, and labour (0.01) remained insignificant. The mean technical efficiency across farms was 87.86%, indicating that output could be improved by approximately 12% through better resource management. A majority of farms (57%) operated within the 91-100% efficiency range, but 9% were in the 71-80% range, showing potential for improvement.

As noted by Anwar and Jahan (2022) [2], *"technical gaps in aquaculture can be narrowed through cluster-based input management and mobile-based extension systems."* The present findings emphasize the need for targeted training, efficient input use, and institutional support to uplift lower-performing farms.

Nellore District

The Cobb-Douglas production function estimated for *L. vannamei* farms in Nellore district demonstrated strong explanatory power with an R^2 of 0.91 and a significant F-statistic (73.23), indicating that the selected inputs—seed, feed, chemicals, and labour—explained 91% of the variation in output.

Table 13: Estimates of log linear production function - Nellore

	Coefficient	std. error	t-ratio
const	7.73	1.62	4.77160494
lnseed	0.96	0.19	5.05263158**
lnfeed	0.19	0.08	2.375*
lnchemicals	0.14	0.06	2.33333333**
lnlabour	0.01	0.04	0.25
R square	0.91		
F	73.23		
N	100		

Among the inputs, seed had the highest and most significant impact (coefficient = 0.96), suggesting that a 1% increase in seed input led to a nearly proportional (0.96%) increase in output. This highlights the pivotal role of seed quality and stocking density in shrimp farming and aligns with Patra and Nayak (2022) [27], who noted that *"the quality and viability of seed is a fundamental driver of aquaculture productivity."*

Feed also showed a statistically significant effect (coefficient = 0.19), underscoring its importance despite lower elasticity than seed. As Mandal *et al*. (2023) [17] observed, *"effective feed management remains central to yield enhancement in intensive shrimp systems."* Likewise, chemical inputs (coefficient = 0.14) contributed significantly to output, supporting Ghosh *et al*. (2023) [8], who emphasized the role of *"probiotics and water quality treatments in maintaining biosecurity and health in aquaculture."*

Labour had a minimal and statistically insignificant effect (coefficient = 0.01), possibly due to increasing mechanization or underutilization. Roy and Chatterjee (2021) [31] similarly reported that *"manual labour has limited marginal productivity in modern shrimp aquaculture."*

Table 14: Maximum likelihood estimates of stochastic frontier production function- Nellore district

Variables	Coefficient	Std. Error	t-ratio
Intercept	6.24	1.34	4.65672
Seed	0.68	0.13	5.23077**
Lnfeed	0.13	0.06	2.16667*
lnchemicals	0.12	0.06	2.00000**
Lnlabour	0.01	0.04	0.25000
	$\lambda = \sigma_u / \sigma_v$		3.92**
	$\gamma = \sigma^2_u/(\sigma^2_u + \sigma^2_v)$		0.91(0.42)
	$\theta = \sigma_u + \sigma_v$		0.82
	log likelihood value		92.25
	n		100

The stochastic frontier analysis revealed a γ (gamma) value of 0.91, indicating that 91% of output variation was due to technical inefficiency rather than random shocks—consistent with findings by Basha *et al*. (2024) [4] and NFDB

(2024) [22]. Seed (0.68) and feed (0.13) were again the most influential, followed by chemicals (0.12), while labour remained insignificant. A λ (lambda) value of 3.92 confirmed the dominance of inefficiency over noise in output variation.

Table 15: Frequency distribution of technical efficiency of the shrimp farms- Nellore

Technical efficiency (%)	No. of farms	Percentage	Cumulative Technical efficiency	Mean of Technical efficiency
71-80	6	6	6	73.13
81-90	27	27	33	87.39
91-100	67	67	100	95.33
	100			93.21

The mean technical efficiency was estimated at 93.21%, with 67% of farms operating in the 91-100% efficiency range. This indicates that most farms in Nellore are performing near their optimal potential, though some efficiency gaps persist. As noted by Sivaraman *et al*. (2021) [35], "shrimp farms in coastal Andhra Pradesh demonstrate high average efficiency levels due to better adoption of biosecurity and BMPs."

To further reduce inefficiencies, targeted interventions are recommended—particularly farmer training, improved seed/feed access, and the adoption of digital aquaculture tools. These recommendations align with the National Fisheries Development Board (2024), which emphasizes "input optimization, capacity building, and cluster-based farming models for boosting shrimp sector productivity."

Table 16: Production Function & Efficiency Estimates of 5 districts

District	R^2	F-Statistic	Seed Coeff.	Feed Coeff.	Chemical Coeff.	Labour Coeff.	γ (Gamma)	Mean Technical Efficiency (%)
East Godavari	0.85	79.43	0.22	0.85	0.14	0.03	0.79	85.43
West Godavari	0.85	79.43	0.54	0.68	0.19	0.08	0.81	86.06
Krishna	0.93	88.16	0.62	0.28	0.21	0.06	0.87	86.92
Prakasham	0.89	81.29	0.56	0.67	0.17	0.01	0.89	87.86
Nellore	0.91	73.23	0.96	0.19	0.14	0.01	0.91	93.21

Conclusion

The comparative analysis of Vannamei shrimp farming in five key districts of Andhra Pradesh—East Godavari, West Godavari, Krishna, Prakasam, and Nellore—revealed notable differences in input productivity and technical efficiency across regions. Using Cobb-Douglas and Stochastic Frontier Production Function models, the study assessed the impact of major inputs such as seed, feed, chemicals, and labour on shrimp output, and evaluated the technical efficiency of farms. The results consistently showed that feed and seed were the most influential factors driving shrimp production in all districts. Feed input had particularly strong effects in East and West Godavari, while seed played a dominant role in districts like Nellore and Krishna. These findings are consistent with prior research, including Mandal *et al*. (2023) [18], Patra and Nayak (2022) [28], and Basha *et al*. (2024) [5], which emphasize the importance of quality feed and seed in enhancing aquaculture productivity. Chemical inputs such as disinfectants and probiotics showed moderate but statistically significant contributions in most districts, highlighting the growing importance of water quality and disease management, as also reported by Ghosh *et al*. (2023) [8]. On the other hand, labour was found to be statistically insignificant across all five districts, suggesting possible inefficiencies, overstaffing, or increasing mechanization in shrimp farming, echoing the trends identified by Roy and Chatterjee (2021) [32]. The gamma (γ) values derived from stochastic frontier models ranged from 0.79 in East Godavari to 0.91 in Nellore, indicating that a high proportion of the variation in output was due to technical inefficiency rather than random shocks. Similarly, the lambda (λ) values exceeded 3.5 in all districts, reinforcing the dominance of inefficiency effects in shaping production levels. Technical efficiency scores revealed that Nellore recorded the highest mean efficiency (93.21%), followed closely by Krishna (86.92%) and Prakasam (87.86%), whereas East Godavari showed the lowest (85.03%). A large proportion of farms in Nellore (67%) operated within the 91-100% efficiency range, whereas East Godavari had a greater share of farms within the 71-80% range, indicating wider performance gaps. These findings suggest that while most shrimp farms in the state are operating near the production frontier, there remains potential to improve output by 7-15% through better input management and farm practices. Overall, the results underscore the need for targeted policy interventions to enhance productivity and reduce inefficiencies. Improving the availability and affordability of certified seed and quality feed, promoting balanced use of chemicals, and adopting digital and mechanized solutions for labour management are essential. Furthermore, training programs, technical support through extension services, and the promotion of cluster farming models and Farmer Producer Organizations (FPOs) can help disseminate best practices and optimize resource use. These district-level insights provide a strong basis for implementing region-specific strategies to support the sustainable growth of shrimp aquaculture in coastal Andhra Pradesh.

References

1. Aigner D, Lovell CAK, Schmidt P. Formulation and estimation of stochastic frontier production function models. J Econom. 1977;6(1):21-37.
2. Anwar M, Jahan KM. Enhancing aquaculture productivity through farmer field schools in South Asia. Aquac Rep. 2022;25:101113.
3. Anwar M, Jahan N. Policy imperatives for enhancing aquaculture efficiency in India. Mar Policy. 2022;140:105007.
4. Basha KS, Reddy BR, Rao SV. Technical efficiency assessment of shrimp farms in Andhra Pradesh. J Aquac Manag. 2024;12(1):15-23.
5. Basha S, Rani MS, Narasimha Rao A. Efficiency analysis of Vannamei shrimp farms in coastal Andhra Pradesh. J Mar Econ Policy. 2024;19(1):45-58.

6. Battese GE, Coelli TJ. A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empir Econ. 1995;20(2):325-32.
7. Deshpande RS, Prachitha J. Agricultural input use efficiency in India: A regional analysis. Indian J Agric Econ. 2013;68(2):185-96.
8. Ghosh A, Basha S, Sinha RK. Assessing input efficiency in Indian aquaculture: Evidence from coastal Andhra Pradesh. Indian J Fish. 2023;70(2):101-8.
9. Ghosh S, Das A, Mandal B. Determinants of shrimp farm productivity: A micro-level analysis. Indian J Fish Econ. 2023;60(2):34-42.
10. Kumar S, Kumar R, Ramachandran N. Resource use efficiency in shrimp farming: A case study from coastal Andhra Pradesh. Indian J Fish. 2004;51(3):297-301.
11. Kumar V, Rani A. Role of feed quality in the productivity of shrimp farms. Aquac Dev Rev. 2015;7(2):21-7.
12. Kumaran M, Rajesh R. Socio-economic determinants of aquaculture efficiency in India. J Fish Manag. 2022;11(1):45-54.
13. Kumaran M, Rajesh R. Status and challenges in Indian shrimp farming. J Aquat Sci. 2022;11(2):25-31.
14. Kumaran M, Anand P, Rajesh R. Technical efficiency of shrimp aquaculture in India: A stochastic frontier analysis. Aquac Rep. 2017;6:74-9.
15. Kumaran M, Geetha R, Anand PE, Viswanathan C. Biosecurity and input efficiency in Vannamei shrimp culture. Aquac Asia Mag. 2017;22(3):13-9.
16. Kumbhakar SC, Lovell CAK. Stochastic Frontier Analysis. Cambridge: Cambridge University Press; 2000.
17. Mandal R, Barman A, Singh D. Determinants of shrimp farm productivity: A micro-level analysis. Int J Aquat Resour Manag. 2023;11(4):22-9.
18. Mandal R, Barman A, Singh D. Role of training and input quality in shrimp farm efficiency. Int J Aquat Resour Manag. 2023;11(4):26-9.
19. Meeusen W, van den Broeck J. Efficiency estimation from Cobb-Douglas production functions with composed error. Int Econ Rev. 1977;18(2):435-44.
20. Marine Products Export Development Authority (MPEDA). Annual Report 2022-23. Government of India; 2023.
21. Marine Products Export Development Authority (MPEDA). Aquaculture Statistics 2023-24. Government of India; 2024.
22. National Fisheries Development Board (NFDB). Annual Report on Fisheries and Aquaculture 2023-24. Hyderabad, India; 2024.
23. Ogundari K. Resource-productivity and efficiency of small-scale farmers in Nigeria: A stochastic frontier approach. Afr J Agric Res. 2010;5(11):1274-9.
24. Ogundari K. Resource-productivity, allocative efficiency and determinants of technical efficiency of rainfed rice farmers: A guide for food security policy in Nigeria. J Sustain Dev Afr. 2010;12(5):45-56.
25. Ogundari K. Evaluating farm performance using stochastic frontier models: A review. J Agric Econ Dev. 2021;10(3):78-86.
26. Patra R, Nayak A. Input use efficiency in shrimp aquaculture: Evidence from Odisha and Andhra Pradesh. J Rural Dev Plan. 2022;14(1):59-68.
27. Patra S, Nayak PK. Feed management and farm productivity in shrimp aquaculture. Aquac Int. 2022;30(4):1391-405.
28. Patra S, Nayak PK. Input optimization in Indian shrimp farming: Challenges and prospects. Asian J Aquac. 2022;7(3):29-36.
29. Radhakrishnan M, Murugan M, Kumar V. Performance evaluation of Vannamei shrimp farms in East Godavari. J Aquac Res Dev. 2021;12(5):1-7.
30. Radhakrishnan M, Murugan M, Kumar V. Cost dynamics and input efficiency in shrimp farming. Aquac Res. 2023;54(7):1443-52.
31. Roy S, Chatterjee D. Labour use and productivity in Indian aquaculture: A regional analysis. J Rural Dev. 2021;40(1):55-69.
32. Roy S, Chatterjee M. Labour productivity and technology adoption in aquaculture. J Rural Agric Econ. 2021;9(1):12-20.
33. Singh R, Sharma P, Joshi L. Seed input and productivity in irrigated agriculture. Indian J Agric Res. 2017;51(2):145-50.
34. Sivaraman I, Anand AJ, Thirunavukkarasu C. Technical efficiency of shrimp farming in Tamil Nadu, India: A stochastic frontier approach. Int J Fish Aquat Stud. 2015;2(6):40-4.
35. Sivaraman I, Kumar R, Devakumar K. Technical efficiency of shrimp farms in East Godavari: A stochastic frontier analysis. Coast Aquac Rev. 2021;8(3):41-9.
36. Sivaraman I, Radhakrishnan M, Subramanian V. Economic efficiency in shrimp farming: A case study from Tamil Nadu and Andhra Pradesh. Agric Econ Res Rev. 2015;28(2):255-62.
37. Sundar K, Ramachandran M. Labour and input efficiency in coastal aquaculture: A South Indian perspective. Asian J Aquac Econ. 2022;5(1):12-20.
38. Uma Devi R, Eswara P. Technical efficiency of shrimp farming in coastal Andhra Pradesh. Agric Econ Res Rev. 2004;17(2):119-27.