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Analysis of Technical Efficiency Levels and Productivity of Seaweed among Smallholder Farmers in Wete District, Zanzibar

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KEYWORDS

Seaweed productivity, Technical efficiency levels

ABSTRACT

Zanzibar experienced substantial variability in seaweed production. Following the existed variability, this study was conducted to analyse technical efficiency levels and productivity of seaweed among smallholder farmers in Wete district, Zanzibar.The study used three-stage cluster sampling and involved 126 farmers. The study used Cobb-Douglas production function, stochastic frontier production function, and multiple linear regression for analysis. Results of the Cobb-Douglas production function showed that seaweed production was significantly influenced by number of lines planted with seaweed ($p < 0.01$), days for using hired labour ($p < 0.05$), and value of capital equipment ($p < 0.01$). Furthermore, results of the Cobb-Douglas stochastic frontier production function showed that the mean technical efficiency level was 60.640%, and this suggesting that output could be increased (using existing resources and technology) by 39.360%. Also, results of the multiple linear regression model showed that seaweed productivity was significantly influenced by household size ($p < 0.05$), farming experience ($p < 0.01$), harvest frequency ($p < 0.05$), sex of a farmer being female ($p < 0.01$), and access to extension services ($p < 0.01$). The study recommends to the Government the need to improve access to extension services to enable seaweed farmers to optimized inputs used, and to invest in affordable machinery and technology.

1.0 Introduction

Seaweeds are classified as macro-algae, and are categorized into three classes based on colour, thus: red, brown, and green seaweed. Regarding seaweed production, Asian continent was a major producer of seaweed, and contributed 348,26750 tons, accounting approximately 97.4% of the world's seaweed production (Leung *et al*., 2021). Furthermore, in 2019, America produced about 487,241 tons of seaweed, while Europe produced approximately 287,033 tone. For the case of Africa, Morocco, Madagascar, and Tanzania were significant seaweed producers in 2019. Morocco produced 17,591 tons of seaweed which contributed to approximately 0.05% of the world's seaweed output (Leung *et al*., 2021). Furthermore, Madagascar produced 9,665 tons of seaweed, accounting for approximately 0.03% of the world has output in 2021 (Cai, 2021). Tanzania produced about 106,069 tons of seaweed, which was approximately 0.30% of the world's output in 2019 (Leung *et al*., 2021).

In Tanzania, seaweed farming is a well-established industry in Zanzibar (RGoZ, 2020). Production of this crop is guided by the 2014 Fisheries and Aquaculture Policy, the policy which seeks to promote sustainable economic growth, environmental stewardship, and improve livelihoods through sustainable utilization of the sea and other blue resources. Figure 1 shows trend of seaweed production in Zanzibar from 2018-2022. Furthermore, Figure 1 shows that seaweed production in Zanzibar has been varying such that production decreased from 10,424.9 tons in 2018 to 8,967.0 tons in 2020, then increased up to 12,593.7 tons in 2022 (Commission of Planning Zanzibar.2023). This variation could have been caused by climatic changes, epiphyte infection,and water quality levels (Mohammed, 2021). Also, seaweed production is affected by farm size, number of seeds, labor availability, investment in equipment, pond conditions, social challenges, institutional challenges, and economic challenges (Irmayani *et al.*, 2015; Banyuriatiga *et al.*, 2017; Muchlis *et al.*, 2020).

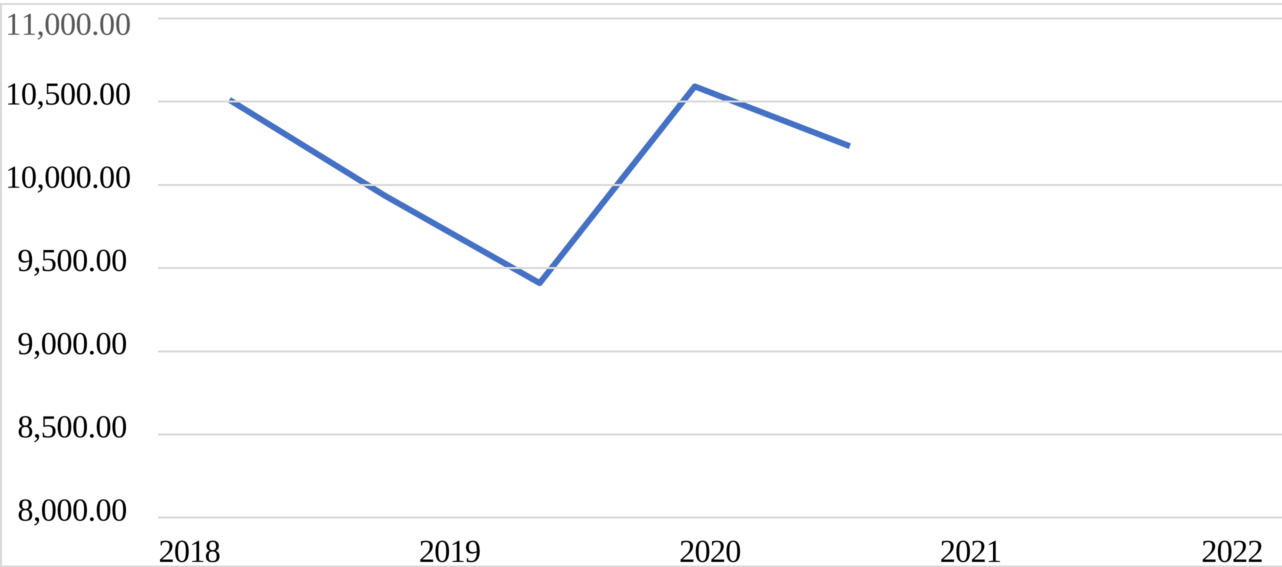

Figure 1: Trend of seaweed production in Zanzibar by tons from 2018-2022

Source: Commission of Planning Zanzibar (2025).

As Zanzibar experiences substantial variability in seaweed production, this suggests the need to analyse productivity and technical efficiency of crop among smallholder farmers. Studies by Jiddawi and Ohno (2020), Msuya and Hurtado (2021), and Zanzibar (2023) did not apply statistical modelling to explain factors which affected seaweed productivity, or explain technical efficiency levels of smallholder seaweed farmers. Hence, the present study was designed to fulfill identified gaps by applying multiple linear regression and stochastic frontier production function to analyse seaweed productivity and technical efficiency levels attained by smallholder farmers in Wete district, Zanzibar. This will harness formation of strategies for improving sustainable production of seaweed as per SDG2, and to ultimately improve livelihood of seaweed farmers as per the 2014 Fisheries and Aquaculture Policy.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in the Wete district, located in Pemba, Zanzibar. Pemba Island. The district lies between latitude 5°03'24" S and longitude 39.720560° E in the south, and latitude -5.056667° S and longitude 39.043410° E in the east. The district comprises of eight wards: Kiungoni, Mjini, Kiyuyu, Kiwani, Kambini, Chwale, Kojani, Fundo, and Gando (BE, 2024). As an island in the Indian Ocean, Pemba is among the top three seaweed producers in Tanzania and significantly contributes to the country's seaweed exports (FAO, 2021).

2.2 Population and Sampling

Population refers to the entire group of individuals or entities about which the research sought to draw inferences and make generalizations (Waples & Gaggiotti, 2006). The study population consisted of all registered agricultural households which engaged in smallscale seaweed production in Wete district of Pemba island. There were 1500 registered agricultural households which engaged in seaweed production (BE, 2024).

The study adopted a three-stage cluster sampling technique, similar to the approach used by Kase (2019) in examining the livelihood aspects of seaweed farming. In the first stage, wards formed a sample of primary units. Simple random sampling was applied to select two wards out of eight wards. In the second stage, villages formed a sample of secondary units. Simple random sampling was applied to select four villages out of ten villages. In the third stage, registered agricultural households which engaged in seaweed farming formed a sample of tertiary units. Simple random sampling was applied to select 126 registered agricultural households which engaged in seaweed farming.

2.3 Data Source

The study used primary data which were obtained through a questionnaire. The questionnaire was administered by using CAPI (Computer-Assisted Personal Interview) during a sample survey. The survey involved a sample of registered agricultural households which engaged in seaweed production in Wete district.

2.4 Variables and Their Measurements

Table 1 presents variables used in the study and their scales of measurements.

Table 1: Variables, measurements, and their scales

Variables	Description	Unit of measurement	Scale
TEY	Technical efficiency	Output/maximum output	Ratio
HLU	No of days for using hired labor	Days	Ratio
QTS	Quantity of seed	Kilograms	Ratio
NLP	Number of lines planted with seaweed	Number	Ratio
CAE	Capital equipment	Tanzania shillings (TZS)	Ratio
OUP	Output of seaweed	Kilograms	Ratio
OVL	Output value of seaweed harvested	Tanzania shillings (TZS)	Ratio

PRV	Productivity (Output of seaweed to number of lines planted with seaweed in a farm)	Kilograms per number of lines planted with seaweed	Ratio
RGR	Sex of the respondent	1=Male 0=Female	Nominal
EDS	Education level	1=Without formal education 2=Primary education 3=Secondary education 4=College/university education	Ordinal
AGE	Age	Years	Ratio
MAS	Marital status of a farmer	1=Married 2=Divorced, 3=Widowed	Nominal
FEX	Farming experience	Years	Ratio
NHV	Number of harvests	Number	Ratio
EXT	Access to extension services	1=Yes 0=No	Nominal
HOS	Household size	Number	Ratio

Source: Authors' compilation (2026).

2.5 Data Analysis

2.5.1 Descriptive statistics

Descriptive statistics was applied to analyse measures of central tendencies and dispersion. Descriptive statistics was applied to compute mean, maximum, minimum, and standard deviation of quantitative variables, and was also applied to prepare frequency distribution tables for categorical variables used in the study. MS Excel and STATA software were used in the analysis.

2.5.2 Multiple regression

Multiple regression is a set of statistical methods used to estimate the relationships between a dependent variable and one or more independent variables. It can assess the strength of these relationships and model their future behavior. Regression analysis has been applied in studies such as Kasim et al. (2019) and Orbeta et al. (2023). Furthermore, it is used to identify associations between variables in datasets, quantifying both the magnitude of these associations and their statistical significance. Regression is a powerful tool for statistical inference and is also employed to predict future outcomes based on historical observations (Taha, 2024). Equation (1) presents the general statistical form of the regression model as follows:

$$Yi = \beta o + \beta i Xi + \varepsilon \qquad (1)$$

Where:

Y=The dependent variable

xi= Vector of the predictor variable.

$\beta 0$= Intercept (constant term).

Bi =Coefficient or slope associated with each predictor variable?

ε = Error term

Moreover, in this study regression analysis was applied to estimate coefficients of the production function in a way that minimized the sum of the squared differences between the observed value of the dependent variable and values of its predictors (Kase, 2019). This was accomplished through the ordinary least squares technique (OLS).

Assumptions of regression analysis:

The linear relationship between the slope and intercept in both dependent and independent variables was essential for meeting the linearity assumption in regression models. This assumption asserted that the regression model must exhibit linearity. The most effective way to assess the linearity assumption was through the examination of a scatter plot (Taha, 2024). Multiple linear regression analysis necessitated minimal or no autocorrelation in the data, implying that the residuals (errors) should not have exhibited correlation across all observations.According to Sarstedt and Mooi (2019), residual values of should follow the normal distribution, thus residuals should have a mean of zero and constant variance.

Heteroscedasticity: This asserts that variability of errors remained constant across observations. When errors exhibited constant variance, they were considered homoscedastic (Sarstedt and Mooi, 2019). Scatter plot of residuals should not demonstrate variability to avoid inefficient parameter estimation.

Multicollinearity: This means that predictors should not be highly correlated with each other as this can cause substantial problems for the regression analysis (Sarstedt and Mooi, 2019). If the model will have a Variance Inflation Factor (VIF) value above 10, it suffers the multicollinearity problem.

Model specification

In this study, multiple regression analysis was applied to model the Cobb-Douglas production function to determine the effect of inputs used on seaweed production. The Cobb-Douglas model was also used by Msuya & A Shimogo (2005).

The Cobb-Douglas production function model specification could be expressed as follows in equation (2):

$$lnOUP_i = \beta_0 + \beta_1 lnHLU_i + \beta_2 lnQTS_i + \beta_3 lnNLP_i + \beta_4 lnCAE_i + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Whereby:

ln = Natural logarithm

OUP_i = The output of the seaweed produced (Kilograms)

HLU_i =Number of days for using hired labor (Days)

QTS_i= Quantity of seeds (Kilograms)

$NLP_{i=}$ Number of lines planted with seaweed on the farm (Number)

CAE_i = Capital of equipment (Tanzanian shillings)

β_0 = Intercept

β_1= Coefficients to be estimated

$\varepsilon_{i=}$ Is the error term

Multiple regression analysis was also employed to analyse the effect of socioeconomic factors on seaweed productivity as follows in equation (3):

$$lnPRV_i = \beta_0 + \beta_1 lnFEX_i + \beta_2 lnNHV_i + \beta_3 lnHOS_i + \beta_4 RGR_{2i} + \beta_5 EDS_{2i} + \beta_6 EDS_{3i} + \beta_7 EDS_{4i} + \beta_8 MAS_{2i} + \beta_9 MAS_{3i} + \beta_{10} EXT_{2i} + \varepsilon_i \quad (3)$$

Wherby:

ln = Natural logarithm

PRV_i = Productivity of the ith seaweed farm (Kilograms per number of lines planted with seaweed)
FEX_i = Experience of the ith seaweed farmer (Years)

NHV_i = Number of harvests per season of the ith seaweed farm (Number)

HOS_i = Household size (Number)

RGR_1= Sex of the seaweed farmer (1=Male, 0= 0therwise) (Reference)

RGR_2= Sex of the seaweed farmer (1=Female, 0= 0therwise)

EDS_1 =Education level(1=Without formal education, 0= otherwise) (Reference)

EDS_2= Education level (1 = Primary, 0 = Otherwise)

EDS_3= Education level (1 = Secondary, 0 = Otherwise)

EDS_4= Education level (1 = College/university education, 0 = Otherwise)

MAS_1= Marital status (1 = Married, 0 = Otherwise) (Reference)

MAS_2= Marital status (1 = Divorced, 0 = Otherwise);

MAS_3= Marital status(1= Widowed, 0 = Otherwise)

EXT_1 =Access to extension services (1 = No,0= Otherwise) (Reference)

EXT_2= Access to extension services (1 = Yes , 0 = Otherwise)

β_0 = Intercept

$\beta_1, \beta_2, ..., \beta_{10}$ = Coefficients

ε_i = Error term

2.5.4 The Stochastic frontier production function

Technical efficiency refers to the ability of a decision-making unit, such as a firm or farm, to produce the maximum possible output from a given set of inputs, or equivalently, to minimize input use while maintaining a given level of output, given the existing technology (Thapa & Dhakal, 2024). Mathematically, technical efficiency is the ratio of output to the maximum output, thus

Technical efficiency=Output/maximum output = (Y_i / Y^*_i) ……………………………………… (4)

Whereby:

The output equation (Y_i) is expressed as follows in equation (5):

$$Y_i = f(X_i; \beta) \exp(V_i - U_i) \quad (5)$$

Y_i being production of the 1^{th} seaweed farm, X_i was a vector of inputs (number of days for using hired labor, quantity of seed, measured,number of lines planted with seaweed on the farm, and capital of equipment) used by the 1^{th} seaweed farm, β being a vector of unknown parameters.

Furthermore, the maximum attained output ($Y*_i$) was expressed as follows in equation (6):

$Y^*_i - f(X_i; \beta)\exp(V_i)$ ………………………………………………………………………… (6)

V_i being a random variable which is assumed to be in.dependently and identically distributed (iid) N (0, σ_v^2) and independent of U_i; U_i being a random variable that is assumed to account for technical inefficiency in seaweed production. U_i is assumed to be independently distributed as truncation (at zero) of the normal distribution with mean ʉ and variance σ_U^2 (Battese and Coelli, 1995). If $U_i > 0$, reflects the technical efficiency relative to the frontier production function; if $U_i = 0$, reflects the technical efficiency lies on the production frontier; if $U_i < 0$, reflects the technical efficiency lies below the production frontier (Msuya and Ashimogo, 2005).

Hence, substituting equations (5) and (6) into equation (4) yields expression of the technical efficiency being $(Yi/ Y*i) = \exp(-U_i)$. ………………………….……………………………… (7)

U_i being the function of factors (age of a farmer, access to extension services, education level of the farmer, number of lines planted with seaweed, farming experience) which affect technical efficiency of seaweed produced.

3.0 Results and Discussion

3.1 Descriptive Statistics

Results presented in Table 2 showed that 17.46% of seaweed farmers were male, while 82.54% were female respectively. These findings indicated that women played a central role in the activity or community under study, whether in farming, household decision-making, or other related domains. The high representation of women reflected existence of gender imbalance seaweed production, suggesting the need for designing interventions for gender balance.

Furthermore, Table 2 showed that 50.00% of the respondents had no formal education, while 19.84% completed primary education. Additionally, 28.57% completed secondary education, and only 1.59% completed college/university/education. These findings indicated that approximately half of of seaweed farmers had no primary education, suggesting the need for formulating strategies for improving literacy skills of these farmers.

Table 2: Descriptive statistics of categorical variables used in the study

Variable	Frequency	Percent
Sex of the farmer		
Males	22	17.46
Females	104	82.54
Total	**126**	**100**
Education level		
Without formal education	63	50
Primary education	25	19.84
Secondary education	36	28.57
University/College education	2	1.59
Total	**126**	**100**
Marital status		
Married	113	89.68

Divorced	7	5.56
Widowed	6	4.76
Total	**126**	**100**
Access to the extension services		
No	41	32.54
Yes	85	67.46
Total	**126**	**100**

Source: Authors' compilation (2026).

Also, Table 2 indicated that the majority of respondents (89.68%) were married, while smaller proportions were divorced (5.56%) or widowed (4.76%). This corresponds to 113 married, 7 divorced, and 6 widowed individuals. These findings suggested that interventions for improving seaweed productivity should involve spouses of farmers to enhance knowledge sharing and joint decision-making in farming practices.

Results presented in Table 2 showed that about 67.46% of respondents had access to extension services, while 32.54% did not. This corresponded to 85 respondents with access and 41 without access to extension. Presence of farmers who lacked access to extension services suggested the need for seaweed stakeholders use mass media or social media to improve access to extension services.

On the other hand, Table 3 presented descriptive statistics for quantitative variables. Firstly, findings presented in Table 3 showed that the mean age of respondents was 47.64 years (SD = 12.79), ranging from a minimum of 22 years to a maximum of 75 years. This indicated that seaweed farming in the area engaged both younger and older farmers. This suggested the need for training young and middle-aged farmers about best practices for seaweed cultivation, and resource management to promote sustainable seaweed production.

Secondly, results presented in Table 3 showed that household size averaged 6.63 members (SD =3.82), thus households had either 6 or 7 members. The size ranged from a minimum of 1 to a maximum of 17 members. This suggested the need to formulate strategies for substituting household labour force in case of out-migration so as to promote sustainable seaweed production.

Table 3: Descriptive statistics of quantitative variables used in the study

Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
Farmer's age (Years.)	47.64	12.79	22	75
Household size (Number)	6.63	3.82	1	17
Lines planted with seaweed (Number)	102.78	23.72	60	160
Number of days for using hired labor (Days)	0.39	2.20	0	20
Quantity of seeds (kg)	3.15	4.68	0	22.86
Capital equipment (TZS)	14,700	2,776.24	7,500	21,600
Farmer's experience (Years)	5.37	2.88	3	12
Number of harvests (Number)	3.39	2.09	1	12
Output value of the seaweed harvested (TZS)	217,159	184,360	20,000	783,000

Source: Authors' compilation (2026).

Thirdly, the results presented in Table 3 showed that the average number of lines planted with seaweed was 102.78 lines in a farm (SD = 23.72), thus a seaweed farms had either 102 or 103 lines planted. Number of planted lines ranged from a minimum of 60 to a maximum of 160, indicating moderate variation in farm size. Findings suggested a need to formulate strategies for optimizing farm area, and as well as for adopting best practices for seaweed farming.

Fourthly, results presented in Table 3 showed that the average number of days for using hired labor was 0.39 days (SD = 2.20), indicating that most farmers relied on family labor. Low utilization of hired labour could have been due to the fact that smallholder seaweed farmers could not afford to pay prevailing market wage rates compared to off-farm entrepreneurs. This suggested the need to use technology to reduce human labour in seaweed production.

Fifth, results presented in Table 3 showed that on average, farmers used 3.15 kg of seeds (SD = 4.68), with a maximum of 22.86 kg, reflecting significant variability in seed input use. This variability suggested need for improving access to seeds and strengthening extension services.

Sixth, results presented in Table 3 showed that the mean value of capital equipment investment was TZS 14,700 (SD = 2,78), and ranged from TZS. 7,500 to TZS 21,600. This suggested the need for improving access to affordable credit facilities or subsidy programs to enable farmers to expand capital investment, and adopt new technology.

Seventh, results in Table 3 indicated that the average farming experience was 5.37 years (SD = 2.88), with and this ranged from 3 to 12 years. This indicates that some seaweed farmers had low experience, while some had a moderate experience. These findings suggested that farmers had to be trained in good agricultural practices for seaweed farming to improve productivity, and access to profitable markets.

Eighth, results presented in Table 3 showed that the average number of harvests averaged 3.39 per year (SD = 2.09), thus average number of harvests were either 3 or 4, and ranged from 1 to 12. This suggested the need for training farmers about seaweed harvesting practices to meet the market demand and standards.

Lastly, results in Table 3 showed that the mean output value of the seaweed harvested TZS 217,158.73 (SD = 184,360.49), and this ranged from TZS 20,000 to TZS 783,000. Findings suggested the need to strengthen farmers' access to reliable market opportunities so as to reduce disparities in income earned. Moreover, promoting cooperative marketing and improving value-chain linkages could have helped farmers to secure prices which yield super profit.

3.2 Factors Affecting Seaweed Production

Results presented in Table 4 showed OLS estimates for parameters of the Cobb-Douglas production function regarding determinants of seaweed production. Results showed that number of lines planted with seaweed, number of days for using hired labour, and capital equipment were significant factors ($p < 0.05$) which influenced seaweed production. Also, results presented in Table4 showed that the Adjusted R^2 was 0.70 implying that 70.00 % of the total variation in the dependent variable was explained by variation in independent variables. So the model was fit for the data as it explained a large proportion of the variance in the dependent variable.

Again, results presented in Table 4 showed that output of seaweed increased significantly with the number of lines planted with seaweed ($p < 0.01$). This implied that 1% increase in the number of seaweed lines planted was associated with 3.07% increase in output, holding other inputs constant. These findings concurred to Ali *et al.* (2022). This suggested that expansion of seaweed farms is through increasing number of lines planted, and this could have served also as a strategy to boost yields.

Moreover, results presented in Table 4 showed that output of seaweed increased significantly with number of days for using hired labor ($p < 0.05$). This implied that for every 1% increase in number of days for using hired labor, output increased by 0.12%, holding other inputs constant. These findings aligned to Banyuriatiga *et al*. (2017) who found that use of labour had positive impact on seaweed production. These findings suggested the need to optimise utilization of hired labour in seaweed farming.

Table 4: Determinants of seaweed production by Cobb-Douglas production function

Variables	Coef.	St. Err.	t-value	p-value
LnNLP	3.07	0.21	14.82	0.00***
Ln HLU	0.12	0.05	2.51	0.01**
Ln QTS	0.08	0.12	0.67	0.51
Ln CAE	0.9	0.24	3.73	0.00***
Constant	-10.92	2.43	-4.48	0.00***

Note: Significance levels of 1%, 5%, and 10% are indicated by ***, **, and * respectively.

R^2= 0.71
Adj R^2 = 0.70
Source: Authors' compilation (2026).

Lastly, results presented in Table 4 showed that output of seaweed increased significantly with value of capital equipment invested ($p < 0.01$). This implied that for every 1% increase in the valued of capital equipment invested, output increased by 0.9%, holding other inputs constant. These findings were similar to Baharuddin (2021) who found that capital had positive impact on seaweed production. This suggested the need to increase investment equipment and machinery to reduce dependence on human labor in seaweed production.

3.3 Analysis of Technical Efficiency of Seaweed Production

Table 5 presents results from the stochastic frontier production function. Results in Table 5 showed that The log likelihood value with the MLE method was greater than the log likelihood value with the OLS method, implying that the model fitted well the data. Furthermore, δ^2 was statistically significant ($p<0.1$) which indicated that the production variation contributed by technical inefficiency (U_i) was 67.58 percent. Moreover, the value of λ was 9.8575 which was >1 suggesting that variations in the seaweed production were caused by smallholder farmers' practices rather than random variability. Furthermore, results in Table 5 showed that the estimated maximum likelihood coefficient for number of lines planted with seaweed was 1.8345, and was significant ($p<0.01$). This implied that an increment of number of lines planted with seaweed by one percent would result an increment of output by 1.8345 percent.These findings agreed to Nguyen et *al.* (2023) who found that efficiency of seaweed production increased with farm size. Jumiati *et al.* (2023) pointed out that the farm, thus sea land, determine farmers' decisions in seaweed production, hence increasing seaweed production could be through intensification or more intensive management of existing sea land.

Table 5: Maximum likelihood estimates for the parameters of the Cobb-Douglas stochastic frontier production function

Variable	Parameter	Coefficient	S.E	p-value
Constant	β_0	14.3998	1.3066	0.000***

LnNLP	β_1	1.8345	0.1460	0.000***
Ln HLU	β_2	0.0036	0.0093	0.701
Ln QTS	β_3	0.0042	0.0052	0.419
Ln CAE	β_4	0.1031	0.1371	0.452
δ^2		0.6758		0.0944*
λ		9.8575		0.0681*
Prob>chi2				0.00
Log likelihood				166.109
LR test (Log-OLS)				0.001

Note: Significance levels of 1%, 5%, and 10% are indicated by ***, **, and * respectively.

Source: Authors' compilation (2026).

Furthermore, Table 6 presents technical efficiency levels of smallholder seaweed farmers based on the Cobb-Douglas stochastic frontier production function. Results presented in Table 6 showed that the minimum estimated technical efficiency level of smallholder seaweed farmers was 14.482 percent while the maximum was 93.391 percent. Furthermore, the mean technical efficiency level was 60.640 percent. Since the mean value of the technical efficiency index was less than 70 percent, it could be categorized as inefficient (Jumiati *et al.,* 2023). Moreover, the mean technical efficiency level being 60.640 percent implied that the output of smallholder seaweed farmers could be increased (using existing resources and technology) by 39.360 percent. These findings showed that smallholder seaweed farmers used their resources and technology somewhat inefficiently. Results suggested a need to improve agricultural extension services, adopt learned seaweed farming techniques, invest more on working capital, equipment, and machinery (Nursan *et al*., 2023; Lumenyela *et al*, 2023;Jumiati *et al.*, 2023). Also, results suggested a need for the government and other stakeholders in agriculture to formulate strategies for enabling smallholder farmers to optimize inputs used in seaweed production.

Table 6: Technical efficiency levels based on the Stochastic Production Frontier

Percent	Frequency	Percent
11%-20%	2	1.59
21%-30%	16	12.70
31%-40%	10	7.94
41%-50%	8	6.35
51%-60%	11	8.73
61%-70%	27	21.43
71%-80%	29	23.02
81%-90%	21	16.66
91%-100%	2	1.58
Total	**126**	**100**
Minimum		14.482
Maximum		93.391
Mean		60.640

Source: Authors' compilation (2026).

3.4 Factors influencing seaweed productivity

Results presented in Table 7 showed OLS estimates for parameters of the regression model regarding determinants of seaweed productivity. Results showed that household size, farming experience, harvest frequency, sex of the seaweed farmer being female, and access to extension services were significant factors ($p <0.05$) which influenced seaweed productivity. Also, results presented in Table 7 showed that the Adjusted R^2 was 0.86 implying that 86.00 % of the total variation in the dependent variable was explained by variation in independent variables. So the model was fit for the data as it explained a large proportion of the variance in the dependent variable.

Furthermore, results presented in Table 7 showed that productivity of seaweed increased significantly with the household size ($p < 0.05$). This implied that for every 1% increase in household size, productivity increased by 0.16% , holding other factors constant. These findings suggested that household members contributed in seaweed farming as unpaid workers. Based on the law of diminishing returns, productivity may decrease in the future if number of farm workers will increase, holding other factors constant (Dwivedi, 2004)

Again, results presented in Table 7 showed that productivity of seaweed increased significantly with the farming experience ($p < 0.01$). This implied that for every 1% increase in farming experience, productivity increased by 2.60%, holding other factors constant. These findings were similar to Obiero *et al.* (2019) who found that increased in farming experience significantly improved seaweed productivity.Based on this evidence, it is recommended that training programs be established to facilitate the transfer of knowledge from experienced farmers to newcomers, thereby strengthening skills and boosting seaweed production.

Table 7: Determinants of seaweed productivity

Variable	Coef.	Std. Err.	t-value	p-value
ln*HOS*	0.16	0.07	2.46	0.02**
ln*FEX_*	2.60	0.08	34.67	0.00***
ln*NHV*	0.22	0.08	2.75	0.01**
RGR_2	-0.36	0.12	-3.13	0.00***
EDS_2	0.08	0.09	0.83	0.41
EDS_3	-0.03	0.09	-0.29	0.77
EDS_4	-0.14	0.23	-0.61	0.54
MAS_2	-0.01	0.15	-0.07	0.95
MAS_3	0.11	0.15	0.73	0.47
EXT_2	0.85	0.10	8.50	0.00***
Constant	4.60	0.23	20.00	0.00***

Note: Significance levels of 1%, 5%, and 10% are indicated by ***, **, and * respectively.

R^2=0.88

Adjusted $R^{2=}$ 0.86.

Source: Authors' compilation (2026).

Moreover, results presented in Table 7 showed that productivity of seaweed increased significantly with the harvest frequency ($p < 0.05$). This implied that for every 1% increase in the harvest frequency, productivity increased by 0.22%, holding other factors constant. These findings were similar to Fausayana *et al.* (2019) who reported that that increased harvesting frequency significantly raised seaweed production in coastal farming systems.This suggested that farmers who harvested more frequently achieved higher annual yields, reflecting the need for effective farm planning and input management. to allows multiple harvest cycles.

Also, results presented in Table 7 showed that productivity of seaweed decreased significantly when sex of the seaweed farmer being female ($p < 0.01$). This implied that for every 1% increase in female farmers, productivity decreased by 0.36%, holding other factors constant. Ramesh *et al.* (2021) found that gender-based differences in agricultural productivity often stem from unequal access to resources and support systems. This implies that there is a need to formulate strategies for improve equal access to resources, and support systems as female farmers have to ration their time also for domestic activities of a household apart from farming activities.

Lastly, results presented in Table 7 showed that productivity of seaweed increased significantly with access to extension services ($p < 0.01$). This implied that for every 1% increase in the access to extension services, productivity increased by 0.85%, holding other factors constant. These findings aligned to Leung *et al.* (2021) who reported that extension services significantly enhanced farmers' performance and technology adoption. This suggested the need for improving technical support services, and training to seaweed farmers.

4.0 Conclusion and Policy Implications

The study sought to analyse technical efficiency levels and productivity of seaweed among smallholder farmers in Wete district, Zanzibar. The study applied multiple regression and stochastic frontier production function for analysis. Results of Cobb-Douglas production function showed that number of lines planted with seaweed, number of days for using hired labour, and value of capital equipment were significant factors ($p <0.05$) which influenced seaweed production. These findings suggested the need to optimize utilization of each factor in seaweed production, and as well as increase investment in equipment and machinery to reduce dependence on human labor. Furthermore, results of Cobb-Douglas stochastic frontier production function showed that the mean technical efficiency level was 60.640 percent, and this implied that the output of smallholder seaweed farmers could be increased (using existing resources and technology) by 39.360 percent. Also, results from multiple regression showed that household size, farming experience, harvest frequency, sex of the seaweed farmer being female, and access to extension services were significant factors ($p <0.05$) which influenced seaweed productivity.These findings suggested the need to improve access to agricultural extension services and use of technology to improve efficiency and productivity among smallholder seaweed farmers. The study recommends also the need to predict factors affecting technical efficiency of seaweed production by using longitudinal data and Machine Learning methods. This will contribute towards formation of strategies for ensuring sustainable production of seaweed as per SDG2.

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References

Ali, M., Sahrina, S., & Yusuf, R. (2022). Analysis of production and income of seaweed farming in coastal areas. International Journal of Agricultural Sciences, 6(1), 45–54.

Arivoli, P., Antony, C., & Ruby, P. (2024). Global seaweed production: Data and trends. *Vigyan Varta*, *5*(10), 61–64.

Baharuddin, A. (2021). The impact of capital investment and labor on seaweed production efficiency. Journal of Marine and Coastal Economics, 8(2), 112–125.

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, *20*(2), 325–332

Bergschmidt, H. (1997). Seaweed production in Kiribati: A new cash crop. *PACIFIC Bulletin*, *10*, 9–12.

Brugere, C., Msuya, F. E., Jiddawi, N., Nyonje, B., & Maly, R. (2020). Can innovation empower? Reflections on introducing tubular nets to women seaweed farmers in Zanzibar. *Gender, Technology and Development*, *24*(1), 89–109.

Cai, J. (2021). Global status of seaweed production, trade and utilization. *FAO Aquaculture Newsletter*, *28*(May), 1–17.

Commission of Planning Zanzibar. (2023). *Mapitio ya hali ya uchumi 2022 na utekelezaji wa mpango wa maendeleo 2022/2023*. Ministry of Finance and Planning, Zanzibar.

Dogeje, F., Msuya, F. E., Ngaruko, D., & Mohamed, A. S. (2024). Blue economy dynamics: Does women's participation in seaweed aquaculture influence their income levels? Empirical evidence from Zanzibar. *Aquaculture International*, *33*(1), 145–162.

Dwivedi, D. N. (2004). *Principles of Economics*. Mzumbe University Library. https://library.mzumbe.ac.tz/vufind/Record/Library1.7730

Fausayana, I., Sani, L. O. A., & Taridala, S. A. (2019). The relationship between harvesting frequency and annual yields of seaweed farming systems. *Journal of Aquaculture Management*, *14*(3), 201–210.

Jumiati, E., Mubarak, A., Ismandari, T., Kusnadi, A., & Kusnadi, E. (2023). Technical efficiency with stochastic production function frontier of seaweed farming in Pantai Amal, Tarakan City. *IOP Conference Series: Earth and Environmental Science*, *1253*(1), Article 012075. https://doi.org/10.1088/1755-1315/1253/1/012075

Largo, D. B., Msuya, F. E., & Menezes, A. (2020). *Understanding diseases and control in seaweed farming in Zanzibar* (FAO Fisheries and Aquaculture Technical Paper No. 662). Food and Agriculture Organization.

Leung, P., Subasinghe, R., Cai, J., & Zhou, X. (2021). Seaweed revolution: Where is the next milestone? *FAO Aquaculture Newsletter*, *63*, 13–16.

Lumenyela, R. A., Magasha, O., & Dimosso, P. (2023). Adoption of seaweed improved farming techniques among farmers in Zanzibar: An application of Adoption and Diffusion Outcome Prediction Tool. *Social Sciences & Humanities Open*, *7*(1), 1–6. https://doi.org/10.1016/j.ssaho.2023.100472

Maina, G., Muhando, M., Limbu, P., Magembe, L., Waters, T., & Jones, R. (Eds.). (2023). *Tanzania seaweed guide: Opportunities for increased productivity, traceability, and sustainability*. The Nature Conservancy.

Makame, M. O., Hamad, A. R., Said, M. S., Mushi, A., & Sharif, K. (2021). Moving seaweed farms from shallow to deep seawater to cope with warming and diseases in Zanzibar: Current socio-economic and cultural barriers. *Journal of Sustainable Development*, *14*(5), 89–102.

Makame, W. H. (2022). *Analysis of the livelihood aspects of the seaweed value chain in Zanzibar, United Republic of Tanzania*. REPOA.

Mohammed, M. A. (2021). Blue economy potentials for indigenous livelihoods in Zanzibar archipelago: Turning a political adage into coastal communities' realities and practices. *International Journal of Marine and Coastal Economy*, *2*(1), 8–14.

Msuya, E. E., & Ashimogo, G. (2005). *Estimation of technical efficiency in Tanzanian sugarcane production: A case study of Mtibwa Sugar Estate Outgrowers Scheme*. Munich Personal RePEc Archive. https://mpra.ub.uni-muenchen.de/3747/

Msuya, F. E. (2006). The impact of seaweed farming on the social and economic structure of seaweed farming communities in Zanzibar, Tanzania. In A. T. Critchley, M. Ohno, & D. B. Largo (Eds.), *World seaweed resources: An authoritative reference system*. ETI Bioinformatics.

Msuya, F. E. (2011). The impact of seaweed farming on the socioeconomic status of coastal communities in Zanzibar, Tanzania. *World Aquaculture*, *42*(3), 45–48.

Msuya, F. E. (2012). *A study of working conditions in the Zanzibar seaweed farming industry*. Women in Informal Employment Globalizing and Organizing (WIEGO).

Msuya, F. E., & Hurtado, A. Q. (2017). The role of women in seaweed aquaculture in the Western Indian Ocean and South-East Asia. *European Journal of Phycology*, *52*(4), 482–494.

Msuya, F. E., Shalli, M. S., Sullivan, K., Tobey, J., & Mmochi, A. J. (2007). *A comparative economic analysis of two seaweed farming methods in Tanzania*. The Sustainable Coastal Communities and Ecosystems Program, Coastal Resources Centre, University of Rhode Island, & Western Indian Ocean Marine Science Association.

Mwakyambiki, S. E. (2024). *Navigating gender challenges in advancing the blue economy: Insights from Zanzibar*. The Mwalimu Nyerere Memorial Academy.

Nguyen, T. H., Van Nguyen, L., & Coastal, P. D. (2023). Efficiency of seaweed production and the impact of marine farm sizing. *Journal of Applied Phycology*, *35*(2), 567–578.

Nursan, M., Husni, S., Yusuf, M., FR, A. F. U., & Widiyanti, N. M. N. Z. (2022). Production efficiency measurement of seaweed cultivation in the specific economic zone of Mandalika, Central Lombok Regency. *Jurnal Biologi Tropis*, *22*(4), 1390–1396. http://dx.doi.org/10.29303/jbt.v22i4.4506

Obiero, K., Waidbacher, H., Nyawanda, B., Munguti, J., Manyala, J., & Kaunda-Arara, B. (2019). Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquaculture International*, *27*(6), 1689–1707. https://doi.org/10.1007/s10499-019-00438-1

Ramesh, P., Kumar, S., & Devi, M. (2021). Gender-based differences in agricultural productivity and unequal resource distribution. *Gender & Society in Agriculture*, *19*(2), 115–128.

Revolutionary Government of Zanzibar (RGoZ). (2023). *Mapitio ya hali ya uchumi 2022 na utekelezaji wa mpango wa maendeleo*. Author.

Ronald, B., Silayo, G. F., & Abdalah, K. J. (2015). Preference sources of information used by seaweeds farmers in Unguja, Zanzibar. *International Journal of Academic Library and Information Science*, *3*(4), 106–116.

Songwe, B. A., Khamis, S. M., Khalfan, M. H., & Msuya, F. E. (2016). Commercial seaweed farming in Zanzibar coastal villages: Potential for innovative and competitive economic growth. *Huria Journal of the Open University of Tanzania*, *22*(1), 14–28.

Sultana, F., Wahab, M. A., Nahiduzzaman, M., Mohiuddin, M., Iqbal, M. Z., Shakil, A., Mamun, A. A., Khan, M. S. R., Wong, L., & Asaduzzaman, M. (2023). Seaweed farming for food and nutritional security, climate change mitigation and adaptation, and women empowerment: A review. *Aquaculture and Fisheries*, *8*(5), 463–480.

Taha, K. (2024). Text regression analysis: A review, empirical, and experimental insights. *IEEE Access*, *10*, 1–8.

Valderrama, D., Cai, J., Hishamunda, N., Ridler, N., Neish, I. C., Hurtado, A. Q., Msuya, F. E., Krishnan, M., Narayanakumar, R., Kronen, M., Robledo, D., Gasca-Leyva, E., & Fraga, J. (2015). The economics of Kappaphycus seaweed cultivation in developing countries: A comparative analysis of farming systems. *Journal of Applied Phycology*, *27*(2), 251–277.

Waples, R. S., & Gaggiotti, O. (2006). What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. *Molecular Ecology*, *15*(6), 1419–1439.

Zhang, L., Liao, W., Huang, Y., Wen, Y., Chu, Y., & Zhao, C. (2022). Global seaweed farming and processing in the past 20 years. *Food Production, Processing and Nutrition*, *4*(1), Article 23. https://doi.org/10.1186/s43014-022-00103-2