PRODUCTIVITY ANALYSIS OF POND AQUACULTURE IN NORTHERN MALAWI: APPLICATION OF THE STOCHASTIC FRONTIER PRODUCTION FUNCTION

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ABSTRACT

In this study, a stochastic frontier production function was applied to estimate both the productivity (technical efficiency) scores and determinants of low productivity (inefficiency) for 96 fish farms in northern Malawi. The study used the Cobb-Douglas model, in which efficiency estimates showed that fish farmers in the region were more technically inefficient, with mean efficiency scores of 29%. The empirical results show that fingerlings and commercial feed are the most significant inputs that affect production. On average, fish production in northern Malawi is carried out under decreasing returns to scale, meaning that an increase in inputs will more than proportionately decrease output. Except for club membership, all inefficiency determinants are negative, although none of the coefficients are significant. It is, therefore, suggested that policy variables such as feed and fingerlings are important determinants of productivity for farms to reduce the existing 71% yield gap. Thus, the government must ensure that the provision of support services to fish farmers, such as the availability of high-quality input suppliers (feed and fingerlings), are readily available, accessible, and affordable.

Keywords: productivity analysis, pond aquaculture, stochastic frontier production function, Cobb-Douglas model, Malawi.

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1 INTRODUCTION

1.1 Overview of Fisheries Status in Malawi

In Malawi, fish are considered the most affordable source of protein, contributing over 70% of the animal protein to the diet of most Malawians. Fish utilized by Malawians mostly come from capture fisheries with aquaculture only contributing about 2% of the total fish supply (Chirwa, Kassam, Jere, & Mtethiwa, 2017). Malawi is one of the highest fish-eating countries, with a per capita consumption of 9.5 kg per year, and it is among the highest fish producers in the SADC region (Government of Malawi, 2021a). Over the past few decades, fish production from capture fisheries has declined, with no prospect for further expansion due to environmental degradation coupled with overfishing and climate change (Government of Malawi, 2021b). Consequently, many Malawians may lack sufficient animal protein in their diets, leading to stunting and other protein deficiency problems. While Malawi has benefited from capture fisheries on Lake Malawi and other smaller lakes, the declining availability of fish per capita from these sources intensifies the need for more investment in aquaculture (Russell, Grotz, Kriesemer, & Pemsl, 2008).

Considering that fish is important to the health of people and the economy of Malawi, the government has prioritized aquaculture as the most viable option to increase fish supply (Chirwa, Kassam, Jere, & Mtethiwa, 2017). Aquaculture production is a sustainable alternative to fish production in Malawi for several reasons. The country is endowed with freshwater bodies such as lakes, reservoirs, and rivers suitable for aquaculture. Utilizing these resources efficiently might enhance fish productivity, which would generally promote sustainable patterns of economic development (Government of Malawi, 2006; Government of Malawi, 2016).

It is estimated that the current demand for fish in Malawi is 183,000 metric tons; however, the total current fish supply is only 141,000 metric tons, which means an annual shortfall of approximately 42,000 metric tons. Although the Government of Malawi prioritized aquaculture through the National Fisheries and Aquaculture Policy (2016-2021) to supplement the declining wild capture fisheries, aquaculture fish production has remained low owing to several factors, including the unavailability of good quality fish feed and fingerlings, inadequate extension services, lack of proper production technologies, and lack of investment financing (Government of Malawi, 2021b; Government of Malawi, 2016).

1.2 Aquaculture Production Systems and Cultured Species

Malawi's aquaculture is dominated by earthen pond culture system. Although aquaculture is currently at an early stage of development, private corporations and fishing communities started pilot projects to determine the feasibility of establishing both small and large-scale cage culture ventures in and around Lake Malawi (Russell, Grotz, Kriesemer, & Pemsl, 2008). Generally, aquaculture in Malawi is primarily subsistence farming dominated by low input-output producers with a few commercial or medium-scale producers throughout the country and typically, a farmer owns between 1 to 3 ponds with an average size of 200 m^2, ranging from 50 m^2 to 1000 m^2 (Mussa, Kaunda, Jere, & Ng'ong'ola, 2019). In general, aquaculture is integrated with horticulture and animal husbandry to some extent. The level of management is low, and family labor is the norm. The main species currently under culture for both small and large-scale aquaculture operations in Malawi are the three tilapia species namely *Coptodon rendalli*, *Oreochromis shiranus*, *Oreochromis karongae* and *Clarias gariepinus*. The three tilapias account for 93% of the total production (Government of Malawi, 2006; Russell, Grotz, Kriesemer, & Pemsl, 2008). Low-quality feed, mainly different types of bran, is used with few farmers having access to commercial feed, and pond fertility is enhanced by the application of low levels of animal manure, although more cost-effective inorganic fertilizer is now used by a few farmers. Lack of access to commercial feed input hinders the growth of small-scale aquaculture in Malawi (Munthali et al., 2022). The final average body weight rarely exceeds 100 g per fish per six-month production cycle. Irrespective of the species used, the average reported production level of small-scale fish farmers is still low, with a mean of 1 ton/ha/year, equating to approximately 20 kg/year for an average 200 m^2 pond (FAO, 2005; Government of Malawi, 2006).

1.3 Aquaculture Development and Production Prospects in Malawi

Fish farming in Malawi started in early 1900 with the introduction of rainbow trout, and the use of indigenous species began in 1956 with the culture of tilapia species. Pond culturing improved in 1957 with the establishment of an experimental station at Domasi in Zomba for the breeding and distribution of fish fingerlings to farmers. In the 1970s and 80s, the aquaculture sector received support from several donors and Non-Governmental Organizations (NGOS), which promoted the adoption of fish farming in Malawi. Commercial aquaculture was first established in 2005 with only two operators: Maldeco and Chambo Fisheries Ltd. (Government of Malawi, 2016; Government of Malawi, 2006).

Malawi lacked proper guidance to foster aquaculture development until 2006, when the National Aquaculture Strategic Plan (NASP) was put in place as a benchmark for all aquaculture-related activities. Since the inception of the NASP, there has been tremendous growth in the aquaculture sector, and currently there are approximately 15,000 fish farmers with 10,000 ponds, translating to a total pond area of 252 hectares (Government of Malawi, 2021a). Malawi has also witnessed the growth of the two large-scale commercial endeavors mentioned above (DFID 2020).

Fish production increased from 800 tons in 2005 to 9000 tons in 2019 (Figure *1*), with a sharp increase in 2017 because of the implementation of the Agricultural Technological Transfer project, which promoted mono sex culture of tilapia and provision of inputs to fish farmers, while overall aquaculture growth has been limited (Munthali et al., 2022; Government of Malawi, 2021a). Despite poor hatchery infrastructure, there has been a steady production of fingerlings amounting to 11 million from both Government Research Centers and the private sector (Government of Malawi, 2021a). In addition, Malawi aquaculture has witnessed the integration of crops and livestock with aquaculture (Munthali, et al., 2022; Nagoli, Phiri, Kambewa, & Jamu, 2009). Although the role of aquaculture in rural livelihoods is recognized as generating additional cash income, improving food security, and having a synergistic effect on net farm production, rural farmers must overcome many socio-economic obstacles to improve pond fish productivity (Government of Malawi, 2006).

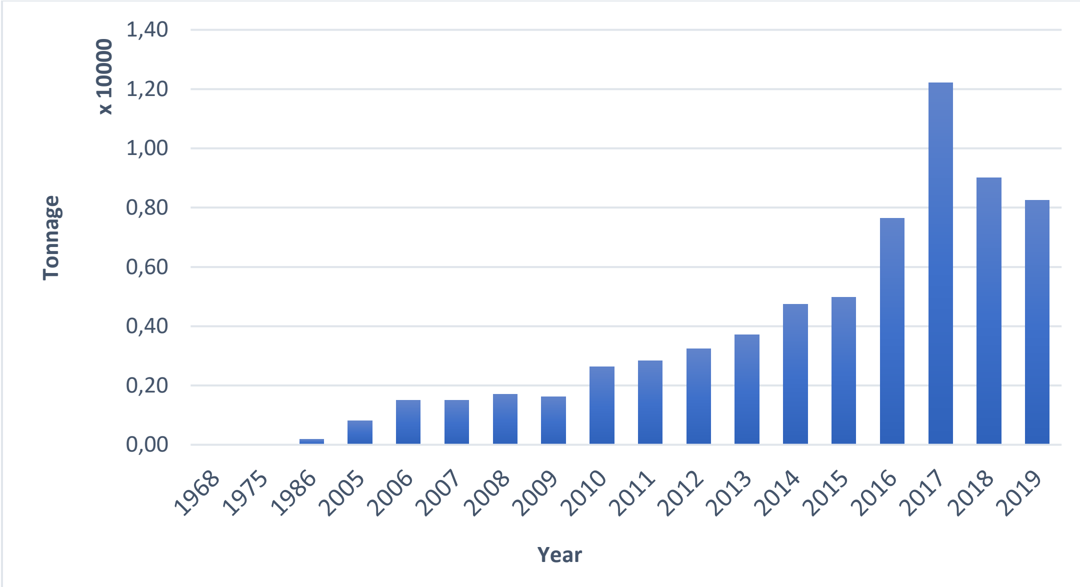

Figure 1. Aquaculture production in Malawi. Source: FishStatJ, 2020

Fish production from both aquaculture and capture fisheries is insufficient to cover the shortfall demand, and Malawi has been importing fish. In 2018 alone, fish imports from Zambia, Zimbabwe, and Tanzania were estimated at US$ 9 million. Therefore, aquaculture must grow at a faster rate than is currently the case. However, it is recognized that appropriate policies and long-term strategies must be put in place whilst developing a responsible aquaculture industry (Mussa, Kaunda, Jere, & Ng'ong'ola, 2019; Government of Malawi, 2021b).

1.4 Issues in Malawi Aquaculture

As previously stated, Malawi has been struggling to commercialize its aquaculture productivity due to several factors, such as the limited supply of quality fingerlings and feed, low stocking density, inadequate extension services, poor production technologies, low participation of large-scale investors, and farming level based on input intensification (Phiri & Yuan, 2018a; Munthali, et al., 2022). Other factors include the non-availability of loan and credit services for producers, high transport costs, poor access to markets, high opportunity costs for commercial start-up, absence of business planning, and lack of capacity to venture into the aquaculture business (FAO, 2005; Munthali et al., 2022). However, Malawi has a great potential for aquaculture growth, which can significantly contribute to the economy of the country. Successful aquaculture development requires productivity or technical efficiency (TE) insight which is the ability of a farm to obtain maximum outputs from a given set of inputs and the allocative efficiency (AE) which is the use of inputs in optimal proportions given their respective prices (Mussa, Kaunda, Jere, & Ng'ong'ola, 2019; Singh, Dey, Rabbani, Sudhakaran, & Thapa, 2009). Improving technical efficiency or productivity can reduce production costs, increase net farm income, and provide a sustainable supply of nutritious foods (Aung, Khor, Tran, Shikuku, & Zeller, 2021).

Despite the potential faced by the Malawi aquaculture industry, over the past decades, the emphasis has been on increasing fish production by promoting adoption of fish farming with less attention on the productivity and efficiency of resource use and the availability of input factors at the farm (Mussa, Kaunda, Jere, & Ng'ong'ola, 2019). The lack of general information relating to aquaculture production analysis in Malawi, which is crucial for the selection of appropriate aquaculture production systems and efficient use of inputs, remains a big challenge. While several studies have been conducted on aquaculture productivity in Malawi, few to date have focused on the production function.

Productivity analysis on fish farms plays a major role, whereby policymakers can provide guidance on the use of resources to promote the greatest return on investment for farmers (Phiri & Yuan, 2018a). Similarly, production analysis is part of the policy evolution process, which allows stakeholders to evaluate alternatives and reach priorities for development actions (Phiri & Yuan, 2018b). Generally, production functions that analyze the productivity or technical efficiency of farms assume that in each system or enterprise type, levels of output can be predicted by a given set of inputs, the mix of inputs which mostly describes the conversion of inputs into output (Asamoah, Nunoo, Osei-Asare, Addo, & Sumaila, 2012).

An understanding of farm productivity is paramount to the development of effective strategies and formulation of policies for small scale aquaculture growth (Asamoah, Nunoo, Osei-Asare, Addo, & Sumaila, 2012). This can help determine which farms maximize output, given a set of inputs that have been used, or minimize the inputs used to produce the same level of output. This measure alone enables identification of the optimal scale of production and technological application across farms over time. Many studies have revealed that technical efficiency provides a reference point for designing economic development strategies for aquaculture production (See, Ibrahim, & Goh, 2021).

Therefore, this study sought to assess resource use efficiency in fish production and identify the optimum combination of various inputs used in aquaculture by fish farmers in Northern Malawi by estimating the parameters of production function and developing evidence-based coherent interventions and policies that will help to improve productivity of the aquaculture industry in Malawi.

1.5 Problem Statement

Regardless of Malawi having a long aquaculture history, the growth of the aquaculture sector has remained stagnant, with low fish production and productivity. Malawi has not been able to develop high-quality feed and fingerling production systems, resulting in a limited supply of these inputs to farmers (Government of Malawi, 2021a; Government of Malawi, 2021b) (Mussa, Kaunda, Jere, & Ng'ong'ola, 2019). Species cultured in Malawi are slow-growing and have poor feed conversion, making the products of aquaculture expensive to produce. This has led fish farmers to pay little attention to the factors of production, such as fingerling quality and quantity, feed quality and quantity, water quality, and managerial skills, resulting in low productivity (Kaunda, 2015). Optimal use of resources in aquaculture is important, especially in developing countries. Among the many factors, increasing the efficiency of resource use and productivity at the farm level may be one of the requirements for sustainable aquaculture. Measuring current productivity or technical efficiency at the farm level, identifying important factors associated with efficient production systems, and assessing the potential sources of future improvements are essential for developing economically viable aquaculture (Khan, Begum, Nielsen, & Hoff, 2021). As the Malawi government continues to enhance aquaculture production through the application of appropriate regulatory measures for sustainable aquaculture development, promotion of aquaculture business, and investment in aquaculture development (Government of Malawi, 2016), farmers will respond by intensifying resource-use efficiency. Therefore, efforts must be made towards aquaculture growth through strategic policy interventions.

1.6 Rationale

The main constraints on aquaculture development include inadequate policies, limited technological advancement, and weak institutional support. This study will contribute to the national aquaculture developmental policy and goals in Malawi. As previously indicated, very few studies have analyzed the technical efficiency of aquaculture in Malawi, although a few findings have revealed that the industry is profitable and worthy of investment (Phiri & Yuan, 2018a). Some researchers have also presented promising results, indicating aquaculture viability in Malawi (Phiri & Yuan, 2018b; Mussa, Kaunda, & Banda, 2016; Mussa R., 2006; Mussa, Kaunda, Jere, & Ng'ong'ola, 2019), however, the aquaculture industry has not taken off despite the potential for growth. Most extension agents and fish farmers in Malawi lack information on how to assess the productivity and profitability of fish farms, which has partially hindered aquaculture development. There is an intrinsic assumption that fish farmers need more inputs to reach their potential; however, it is also known that an increase in aquaculture may be attained through the improvement of productivity, which can be increased through one or a combination of factors. For example, the type of production technology used, the quantity of resources used, and the efficiency with which these resources are used (Phiri & Yuan, 2018a).

It is also well known that efficient farms produce more output than others for a given set of inputs or produce a given output with a minimum level of inputs. Improvement in farm efficiency is an important factor of productivity growth in areas where resources are scarce (Singh, Dey, Rabbani, Sudhakaran, & Thapa, 2009). Correspondingly, in an economy where resources are scarce and opportunities for new technologies are lacking, efficiency studies show that it is possible to raise productivity by improving efficiency without increasing input resources or developing new technologies (Akanbi, 2015).

Despite the potential for small-scale aquaculture development in Malawi, a relevant question for aquaculture policymakers is how best the small-scale aquaculture sector can be more productive by achieving either the current output level with fewer inputs or more output with the current input level. Answering this question is imperative and requires a better understanding of farmers' current production levels and factors that influence productivity.

Identifying technical efficiency is important for policymakers to restructure existing production processes. An understanding of the technology of production is central to the development of realistic theories and the formulation of a wide range of policies and any successful aquaculture development requires knowledge of technical efficiency (TE) (Asamoah, Nunoo, Osei-Asare, Addo, & Sumaila, 2012). Therefore, the results of this study will help the government and other developmental agencies to promote effective combinations of resources to increase output and productivity in the fish farming industry. This will help policymakers and stakeholders in planning, designing, and formulating economic development strategies for aquaculture programs that tend towards increased resource availability and affordability. Moreover, this study will also serve as relevant literature for tertiary institutions and aquaculture extensions for assessing pond aquaculture production systems, among others, by establishing best management practices for farmers to increase aquaculture production, which could benefit food security, income generation, and poverty alleviation. Eventually, this will help attain the goal of the Malawi Growth Development Strategy and Malawi Agenda 2063, which emphasizes food security, creation of employment, wealth, and reduction of poverty through sustainable socioeconomic development and inclusive economic growth (Munthali et al., 2022).

1.7 Research Objectives

This study sought to assess current aquaculture productivity through production function analysis to determine the best decisions for investment in aquaculture.

1.7.1 Specific Objectives

i. To estimate the rate of productivity or technical efficiency of cultured fish farms in the study area
ii. To identify the independent variables or determinants of technical efficiency in the study area
iii. To establish the dependent variables or technical inefficiency determinants of pond culture production in the study area
iv. To evaluate the returns to scale in pond culture production in the study area

2 LITERATURE REVIEW

2.1 Definitions and Determination of Technical Efficiency

Technical efficiency is the ability of a decision-making unit to obtain the maximum output from a given set of inputs and technology measured in a specific way, and any change in these specifications will affect the measure. It is a measure of how efficiently resources are combined and utilized to achieve the desired output. In the deterministic production function, producers consider a technology technically efficient if it produces a higher output than any other alternative technology for all inputs. This efficiency can be measured in terms of the input or output orientation. Input-oriented efficiency identifies time as a target point that maximizes the proportional reduction in inputs or produces a given level of output from an optimal combination of inputs. Whilst output-orientated efficiency looks at an angle that maximizes the proportional reinforcement in outputs or produces the optimal output from a given set of inputs (Coelli, Rao, O'Donnelli, & Battese, 2005; Battese & Coelli, 1995; Battese & Coelli, 1993; Kumbhakar & Lovell, 2000).

As shown in Figure *2* below, the line ‘OF’ represents production frontier that may be used to define the relationship between the input and the output. The production frontier represents the maximum output attainable from each input level; hence, it reflects the current state of the technology in the industry. Farms operate either on that frontier if they are technically efficient, or beneath the frontier if they are not technically efficient. Point 'A' represents an inefficient farm whereas points 'B' and 'C' represent efficient farms. A farm operating at 'A' is inefficient because technically it could increase output to the level associated with the point 'B' without requiring more input. The technical efficiency measurement is between zero and one and a firm is completely technically efficient if its technical efficiency score is equal to one and vice versa (Coelli, Rao, O'Donnelli, & Battese, 2005).

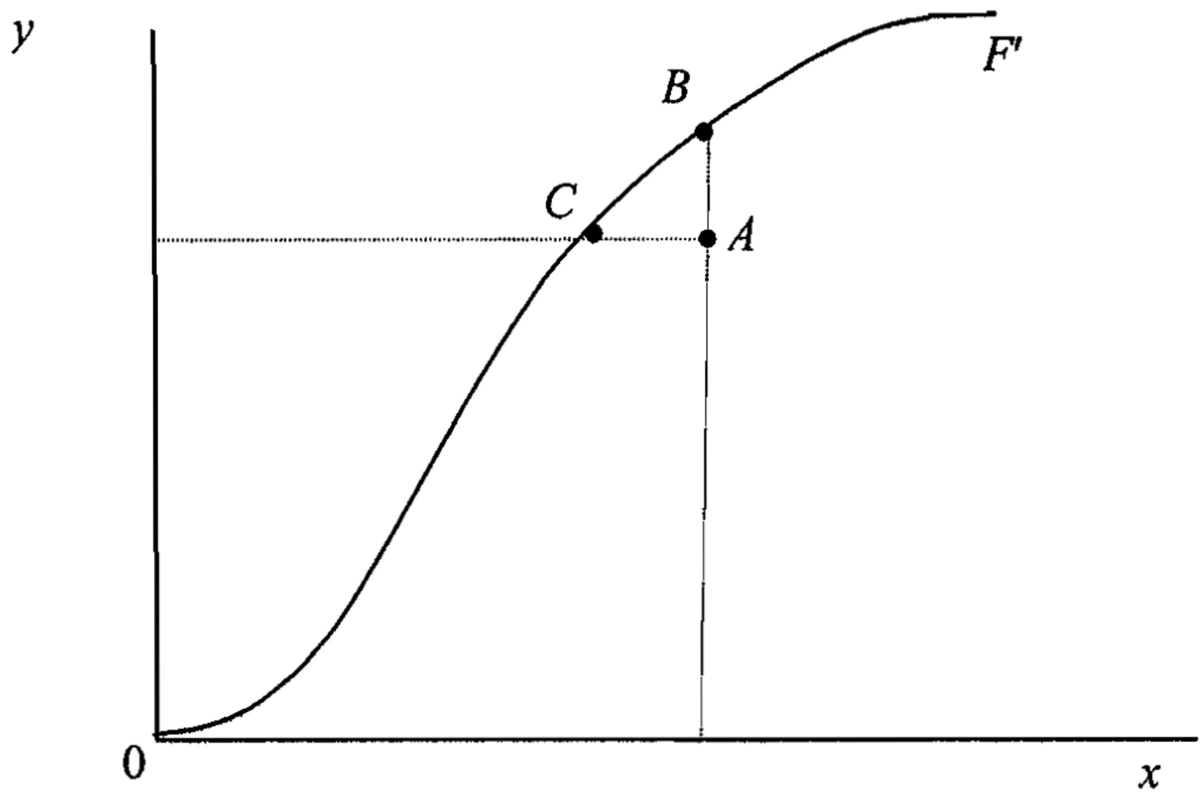

Figure 2. Production Frontiers and Technical Efficiency (Source: Coelli, et al., 2005)

2.1.1 An Application of Stochastic Frontier Production Approach

Frontier production techniques have been widely used to measure productivity performance in aquaculture and various industrial developments. Production frontiers are estimated using non-parametric data envelopment analysis (DEA) or parametric stochastic frontier analysis (SFA). Data envelopment analysis uses mathematical programming to construct the frontier and calculate the relative firm or decision-making unit, while Stochastic Frontier Analysis relies on econometric methods to estimate relative firm efficiencies. Through the Stochastic Frontier Analysis model and technical efficiency estimates, some policy measures and guidelines can be suggested to enhance production (Battese and Coelli, 1993; Battese and Coelli, 1995; Coelli, Rao, O'Donnelli, & Battese, 2005).

2.1.2 Determinants of Technical Efficiency and Technical Inefficiency

Previous studies have shown that the main factors influencing fish yield or output are the stocking rate, feed, fertilizer/manure, labor, and pond area. The use of these inputs has been found to be technically efficient in various firms. Increasing and decreasing the quantities of these inputs would increase farm productivity and profitability and the significance of these input uses have considerable policy implications (Phiri & Yuan, 2018a; Crentsil & Ukpong, Production Function Analysis of Fish Production in Amansie-West District of Ghana, West Africa, 2014; Asamoah, Nunoo, Osei-Asare, Addo, & Sumaila, 2012; Singh, Dey, Rabbani, Sudhakaran, & Thapa, 2009; Iliyasu, Mohamed, & Terano, 2016; Ogundari, K, & Ojo, 2009; Aung, Khor, Tran, Shikuku, & Zeller, 2021; Adeleke, Anderson, Moodley, & Taylor, 2020; Akanbi, 2015). Similarly, factors such as farmers' age, experience, training, farmer club association, frequency of contact with extension workers, educational level, household size, farm status, access to credit facilities, access to markets, adaptation of technology, integrated farming, source of fingerlings, source of feed, pond culture system, and water quality management techniques may be responsible for technical inefficiency at the farm level (Iliyasu, Mohamed, & Terano, 2016; Ogundari, K, & Ojo, 2009; Asamoah, Nunoo, Osei-Asare, Addo, & Sumaila, 2012; Ibrahim, & Goh, 2021; Singh, Dey, Rabbani, Sudhakaran, & Thapa, 2009).

In the study, "Technical efficiency of tilapia production in Malawi and China," Phiri & Yuan (2018a) revealed that feed input is key to improved tilapia production in Malawi whilst results of technical inefficiency estimates show that all determinants of inefficiency which are age, household size, education and pond size, except aquaculture experience had positive signs even though none of the coefficients was significant. Mussa et al (2019) found that the determinants of tilapia output in central and southern Malawi are fingerlings, fertilizer or manure and farm size and further observed that sex of producer, age, household size, access to extension, training and access to credit are major factors influencing the efficiency level of tilapia producers in Malawi.

Ghana found that increasing the fingerling stocking rate and decreasing the quantities of fertilizer, feed, and labor would increase farm profitability. Proportionately higher fish yield can be obtained using more inputs, that is, intensifying production methods (Asamoah, Nunoo, Osei-Asare, Addo, & Sumaila, 2012). A similar study, with the employment of a single stage stochastic frontier approach, found that feed, fingerlings and labor influenced technical efficiency positively and significantly, however education, club membership and extension services negatively influenced technical inefficiency (Crentsil & Ukpong, Production Function Analysis of Fish Production in Amansie-West District of Ghana, West Africa, 2014).

Study results in Malaysia indicated that farmers' experience, contact with extension workers and household size have positive and statistically significant impact on technical efficiency (Iliyasu, Mohamed, & Terano, 2016).

A study in Bangladesh revealed that feed and labor had a positive and significant impact on production, while access to extension services had a positive effect and increased farm efficiency. Generally, efficient farmers are large-scale farmers who use a lower stocking density but a higher feeding intensity, which results in a higher yield. The results further suggested that access to extension services, training, and credit reduces inefficiency significantly (Khan, Begum, Nielsen, & Hoff, 2021). In another study in Bangladesh, the results suggested that feed and stocking density were the most significant factors influencing fish production, however, the use of labor was found to be inefficient in some farm categories (Ali, Rahman, Murshad-e-Jahan, & Dhar, 2018).

In Nigeria, a study result indicated that extension, education, fingerlings stocking density, and access to credit significantly influenced the technical efficiency of farms, while other variables such as age and years of experience showed negative effects on technical efficiency (Ogundari, K, & Ojo, 2009). In India, technical efficiency results revealed that there was potential for increasing fish productivity by increasing the pond area, stocked fingerlings, and labor (Singh, Dey, Rabbani, Sudhakaran, & Thapa, 2009).

3 METHODOLOGY

3.1 Study Area

Malawi is divided into three regions namely, the Northern, Central, and Southern regions. The study area covered five districts spanning the northern part of Malawi, namely Chitipa, Karonga, Rumphi, Mzimba, and Nkhata Bay (Figure *3*). This is the first small-scale aquaculture survey in Northern Malawi to capture production across the entire region, rather than focusing on one district or study site. These districts cover approximately 26,900 km^2 of Malawi's total area and have a high potential for aquaculture development in Malawi.

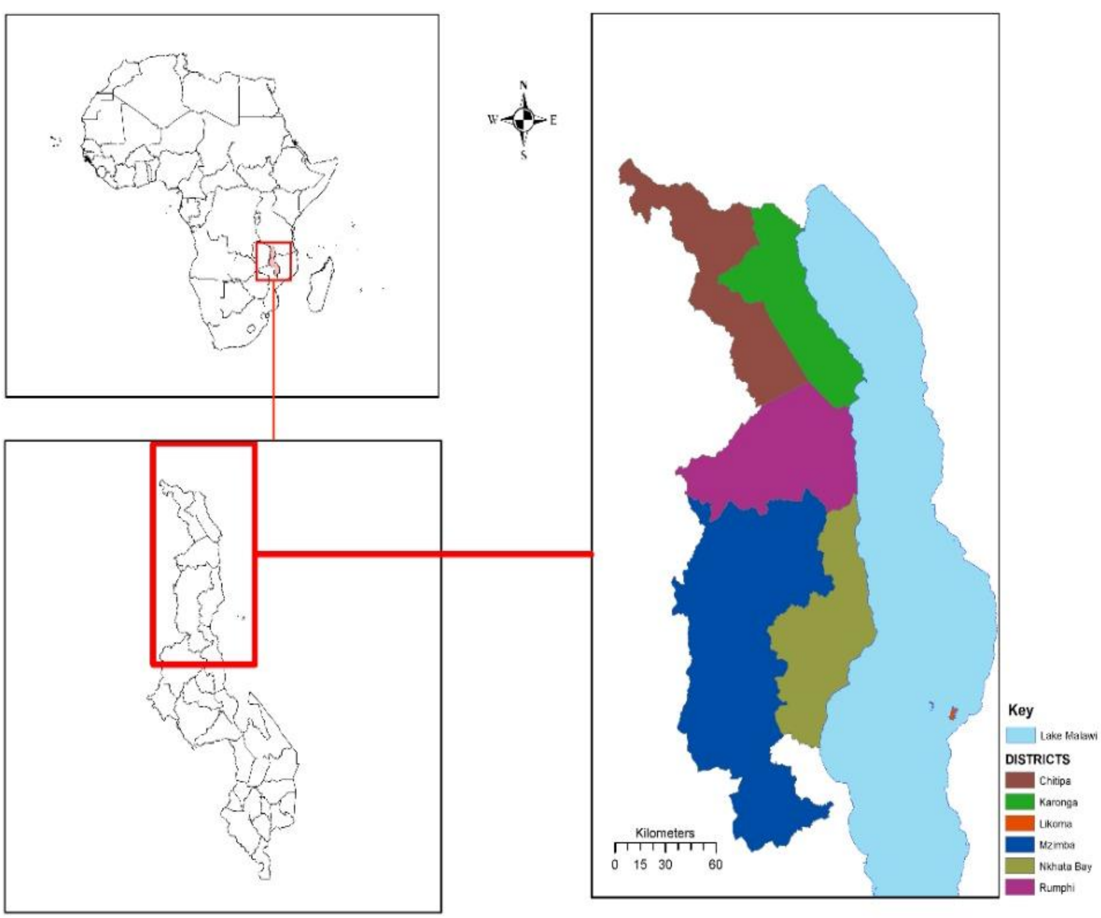

Figure 3. Map of Northern Malawi

3.2 Sampling Procedure and Sampling Size

To generate economic data, the study targeted 100 small-scale fish farmers obtained from the Malawi Department of Fisheries, who were selected through simple random sampling. To determine the statistical sample size, the following formula was used to select the total number of fish farmers (n):

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\mathbf{1}+\boldsymbol{N} * \mathcal{E}^{\mathbf{2}}} \quad \ldots\ldots (1)$$

where N is the total number of fish farmers in the district, and $\mathcal{E}^2$ is a desired margin of error (Nguyen & Simioni, 2020). In this study, the error was fixed at 10%; therefore, the sample size was 100 fish farmers.

The farmers were interviewed in December 2021 using a structured questionnaire. Data and information collected included demographic characteristics of households, such as gender, age, education level, club association, access to extension and credit services, fish farming experience, training, and total household expenditure per year. Data collected on aquaculture production characteristics included the number of ponds owned, total pond area, stocked fingerlings, feed quantity, applied manure quantity, labor in man-days, access to market, integrated fish farming, production level, fish sales, previous climate shocks, and measures against climatic shocks. Informed consent was obtained from each study participant before commencement of the interview. The enumerator briefly explained the purpose of the study, the risks and benefits of participation, and conditions of confidentiality. Participatory, qualitative, and quantitative methods were combined for primary data collection. The data collection exercise was coordinated by the Mzuzu Aquaculture Center in collaboration with the District Fisheries Offices in the Northern Region.

3.3 Data Analysis

In this study, the Stochastic Production Frontier Model (SPF) was used. The SPF approach is an efficiency-estimate model that has been employed in recent studies to simultaneously estimate the parameters of SPF and technical efficiency models. Stochastic production frontier and technical efficiency models have been widely used to determine farm-level efficiency in developing countries for efficiency measurement and the subsequent development of several approaches to efficiency and productivity assessment. The most basic method of technical efficiency is to map a production frontier (statistically or non-statistically, parametrically or nonparametrically), find the locus of maximum output levels associated with given input levels, and estimate farm-specific technical efficiency as a deviation from the fitted frontier as illustrated in Figure *2*. Production Frontiers and Technical Efficiency (Source: Coelli, et al., 2005) (Coelli, Rao, O'Donnelli, & Battese, 2005).

There are two approaches to analyzing the determinants of technical efficiency or inefficiency. Several authors first estimated stochastic frontiers to predict firm-level efficiencies, and then regressed these predicted efficiencies on farm-specific variables to explain variations in output between firms in an industry (See, Ibrahim, & Goh, 2021; Coelli, Rao, O'Donnelli, & Battese, 2005). This is usually referred to as the two-stage procedure. However, several economists have criticized this procedure, arguing that socioeconomic variables should be incorporated directly into the estimation of the production frontier model because such variables may have a direct influence on production efficiency. To overcome inconsistencies in the assumptions regarding the independence of inefficiency effects in this two-stage estimation procedure, other authors have proposed a single-stage stochastic frontier model in which the inefficiency effects (U_i) are expressed as an explicit function of a vector of farm-specific variables and a random error. However, despite these criticisms, many studies have used a two-stage approach, and approximately 800 published articles and working papers have followed a two-stage approach for measuring efficiency (Coelli et al., 2005). However, this study employs a single-stage stochastic frontier model to estimate farm technical efficiency and its associated inefficiency factors. The parameters were estimated using the following formulae and functions, and the SPF with two error terms was modelled as

$$\boldsymbol{Y_i = f(X_i\beta)\exp(V_i - U_i)} \quad \text{..........} (2)$$

Where Y_i is the production of the i-th farm (i = 1,2,3..............n); X_i is a (1 × k) vector of functions of input quantities applied by the i-th farm; β is a (k × 1) vector of unknown parameters to be estimated; these are random variables assumed to be independently and identically distributed (iid) as $N(O,\delta^2_v)$ and independent of U_is; U_is are non-negative random variables associated with technical inefficiency in production assumed to be independently and identically distributed (iid) as truncation (at zero) with mean $Z_i\delta$ and variance σ^2_u (U~|N($Z_i\delta$, $\sigma^2{}_2$)|); Z_i is an (m × 1) vector of farm-specific variables associated with technical inefficiency; δ is an (m × 1) vector of unknown parameters to be estimated (Coelli, Prasada Rao, O'Donell, & Battese, 2005).

Following the technical inefficiency effects, U_i in equation (2) is expressed as:

$$\boldsymbol{U_i = Z_i\delta + W_i} \quad \text{..........} (3)$$

Where W_i are random variables defined by the truncation of the normal distribution with zero mean and variance σ^2_u, such that the point of truncation is at $Z_i\delta$, that is, $W_i \geq - Z_i\delta$.

The maximum likelihood estimates (MLE) of the model parameters defined in equations (2) and (3) were estimated using the Frontier 4.1 package. The efficiencies were estimated using a predictor based on the conditional expectation of *exp (-U)*. In this process, the variance parameters σ^2_u and σ^2_v are expressed in terms of parametrization.

$$\boldsymbol{\sigma^2 = (\sigma^2{}_u + \sigma^2{}_v)} \quad \text{..........} (4)$$

And

$$\boldsymbol{\gamma = (\sigma^2{}_u / \sigma^2)} \quad \text{..........} (5)$$

The value of γ (Equation 5) ranges from 0 to 1, with values close to 1 indicating that the random component of the inefficiency effects makes a significant contribution to the analysis of the production system.

3.4 Model Specification

Several functional forms have been developed to measure the physical relationships between inputs and output. The most common form in practice is the Cobb-Douglas (CD). Therefore, the stochastic production frontier was estimated using the Cobb–Douglas functional form, as specified below:

$$\boldsymbol{lnY_i = \beta_0 + \sum_{k=1}^{n} \beta_k lnX_{ki} + V_i - U_i} \ldots \quad (6)$$

where subscript *i* refers to the *i*th observation in the sample (*i* =1,2,3….20), *ln* represents the natural logarithm, *and* β_o *and* β_k are the parameters to be estimated. *Y* is observed farming system output (expressed in kg). X_i represents the total number of stocked fingerlings, X_2 is the total amount of feed used in the production cycle (expressed in kg), X_3 is the total labor used during the production cycle expressed in man-days, X_4 is the total amount of manure and fertilizer applied expressed in kg, X_5 is the total pond area expressed in m^2, and V_i and U_i are the noise and inefficiency, respectively.

3.5 Economies of Scale

The elasticity of scale measures the percentage change in output, with a simultaneous percentage change of equal magnitude for all inputs. The elasticity of scale is the sum of the factor elasticities in the production function:

$$\boldsymbol{\mathcal{E} = \sum \beta i)} \ \mathbf{I} = 1\ldots., n \quad (7)$$

Ɛ is constant if β_i is constant, i.e., if the elasticity for X_I is independent of the quantities utilized of all X_i (i = 1, ..., n) and the production function is a homogeneous function. If the production function is homogeneous and Ɛ = 1, then the function is said to be homogeneous of degree one. If Ɛ depends on the level of inputs, then returns to scale differs from point to point on the production surface and the function is said to be homothetic. The production function is said to exhibit increasing returns to scale if Ɛ >1 i.e., a simultaneous increase in all inputs by a certain percentage result in greater percentage increase in output. If Ɛ = 1, the production function exhibits constant returns to scale, i.e., a simultaneous increase in all inputs by a certain percentage result in an increase in production by the same percentage. If Ɛ <1, the production function exhibits decreasing returns to scale i.e., proportional increase in output is less than the proportional increase in all inputs (Kurbis, 2000).

4 RESULTS

4.1 Data Exploration

The aim of this section is to determine the behavior of the independent variables in relation to the dependent variable through the input/output relationship. Simple scatter diagrams were plotted using Microsoft Excel. Four fish farmers that appeared to be outliers in the 100-target sample were removed, leaving a sample size of 96 fish farmers.

4.2 Demographic Information of Fish Farmers

Socioeconomic characteristics and farmer-level information provided by the 96 fish farmers are presented in Table *1*. Male farmers accounted for 68.8% of the pond fish farmers. The lower number of female owners of farms might be because traditionally men are deemed to be the heads of the household unit, and farms operated by a family are likely to be in the name of the head of the family. The results also indicate that about 95% of the farmers were members of the club and had contact with extension agents. It was also observed that 91% of farmers had undergone training in fish farming. 57% had access to good-quality fingerlings, while 25% had access to commercial feed. Of the sampled farmers, 68.8% were small-scale fish farmers, with a total pond area below1000 $m2^2$. Regarding fish farming practices, 93% of farmers were engaged in integration farming, while 22% had access to credit facilities. 77% of sampled fish farmers experienced climate change events, including floods, erratic rainfall, and extremely high temperatures, and only 44% of these farmers implemented adaptation strategies such as early fish harvesting, pond fencing, and rainwater harvesting.

Table 1. Demographic characteristics of fish farmers in the Northern Region of Malawi

	Category	**Frequency**	**Percentage**
Gender	Female	30	31.2
	Male	66	68.8
Club membership	Member	91	94.8
	Non-member	5	5.2
Extension access	Yes	91	94.8
	No	5	5.2
Training	Yes	87	90.6
	No	9	9.4
Fingerling source	Certified	55	57.3
	Others	41	42.7
Pond area	$<1000m^2$	66	68.8
	$>1000m^2$	30	31.2
Feed type	Commercial	24	25
	Others	72	75
Integration	Yes	89	92.7
	No	7	7.3
Credit access	Yes	21	21.9
	No	75	78.1
Climate change impact	Yes	74	77
	No	22	23
Climate change mitigation	Yes	42	43.8
	No	54	56.2

4.3 Definition of Variables

Table *2* presents the measurement of the output and input variables in the Stochastic Production Frontier (SPF) and technical inefficiency models. In this study, one output, five inputs, and two input dummy variables were used to measure technical efficiency. The output represents the quantity of fish produced by the farmers, measured in kilograms. The inputs included the number of fingerlings stocked, feed, labor, manure, pond size, and dummy variables of feed and pond area. The feed variable was measured as the quantity of feed used in kilograms. The labor variable represents the number of hours spent working on farms, measured in man-days. The manure variable was measured as the quantity of manure applied in kilograms, and the pond size variable was measured as the total pond area for production in square meters. The feed dummy variable (D_1) was measured as 1 = commercial feed and 0 = otherwise, while the dummy for pond area variable (D_2 – farming level) was measured as 1 = medium scale and 0 = small scale. The inefficiency determinants include farmers' age, education level, club membership, extension services, experience, training, access to credit facilities, and access to the market.

Table 2. Measurement of output and input variables in the SPF and technical inefficiency model for fish farmers

Variable	**Description**	**Unit**
Y	Total production for the sample farms	Kg
Variables in the frontier		
X_S	Number of fingerlings stocked	
X_F	Amount of feed used	Kg
X_L	Quantity of labor employed	Man-days
X_M	Amount of manure applied	Kg
X_P	Total pond area	M^2
D_1	Dummy for feed (1=commercial, 0= otherwise)	
D_2	Dummy for farming level (1= medium scale, 0=small scale)	
Variables in the inefficiency function		
Z_{AGE}	Age of fish farmers	Years
Z_{EL}	Education level	Years
Z_{CM}	Club member (1= Yes, 0= No)	
Z_{ES}	Extension services (1= Yes, 0= No)	
Z_{EXP}	Experience of farmers in aquaculture	Years
Z_{TR}	Training in fish farming (1= Yes, 0= No)	
Z_{CR}	Access to credit (1= Yes, 0= No)	
Z_{MA}	Access of fish products to the market (1= Yes, 0= No)	

4.4 Sample Characteristics

Table *3* presents the summary statistics of the relevant variables for the fish farmers. The table reveals that considerable variation exists among the farms in terms of production practices and the socioeconomic attainments of the farmers within their respective farms. The mean output from the farms was 57.59 kg, ranging from a minimum of 10 kg to 300 kg. The main inputs of seed, feed, labor, and manure were 2,377 fingerlings, 506.01 Kg, 545.63 man- days and 216.11 Kg respectively. The pond area ranged from 42 m2 to 6,000 m^2 (Figure *4*). For inefficiency factors, age averaged 44.06 years which was within the range of 19 to 71 years, while education had an average of 9.44 years, with most of the farmers having studied beyond primary school education, apart from having 8.52 years of experience.

Table 3. Summary statistics of the quantitative variables

Name of variable	Mean	SD	Range	Min	Max
Expected yield (kg)	57.59	52.79	290	10	300
Fingerlings	2377	26.53	14830	50	14880
Feed (Kg)	506.01	505.46	2375	25	2400
Labor (man-days)	545.63	427.12	1980	180	2160
Fertilizer (Kg)	216.11	207.64	1095	5	1000
Pond size (m2)	1006.31	1096.02	5958	42	6000
Age (years)	44.06	0.47	52	19	71
Education	9.44	2.89	16	0	16
Experience (years)	8.52	0.42	29	1	30

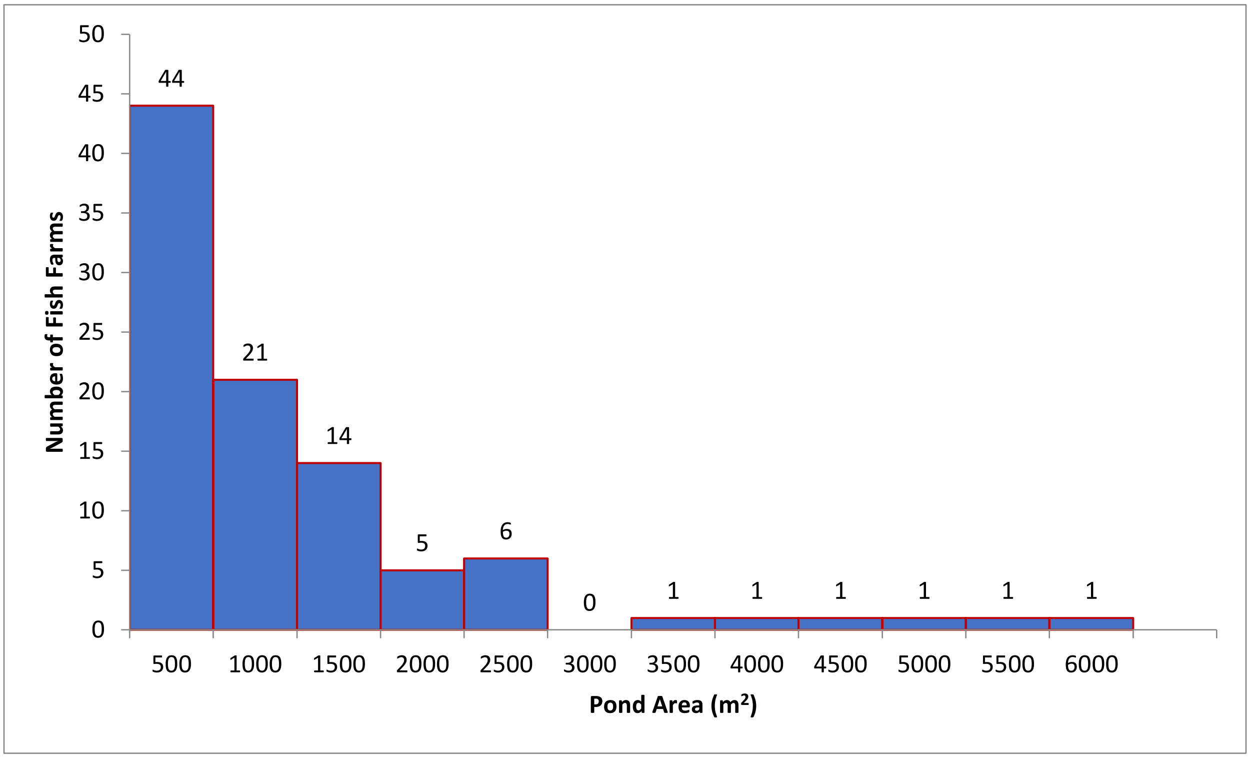

Figure 4. Distribution of fish farmers by pond area: <1000m^2 (small scale), >1000m^2 (medium scale).

4.5 Hypothesis Testing

The sigma squared (σ^2) which is an indication of goodness of fit, was statistically significant at the 1% level (Table *4*), showing the goodness of fit of the survey with the model used and the correctness of the specified coefficients. Y is the measure of inefficiency in the variance parameter, which ranges from zero to one. To test the null hypothesis that there was no significant technical inefficiency, the observed variations in the technical efficiency estimates were simply random or systematic ($H_0 = 0$). An estimated γ parameter, which measures the variability of the two sources of error, was statistically significant at the 1% level, suggesting that 99% of the total variation in total production was related to inefficient error terms, and 1% of the total variations was attributed to stochastic random errors. This implies that the variation in total production among the different farmers was due to differences in their production inefficiencies. In other words, the variation in the output is attributable to factors under the control of farm units much more than to stochastic factors.

4.6 Technical Efficiency Determinant Estimates

Table 4 (below) presents the respective individual coefficients and corresponding t-ratios for the stochastic production frontiers for fish farmers. The results show that all the elasticity of production coefficients, except labor and pond size, have the expected a priori positive sign. Fingerlings had a positive and significant coefficient at 10%. Feed and manure had a positive coefficient but were not significant, whereas the dummy variable for feed (D_1) had a positive significant coefficient at1%. Labor, pond size, and the dummy variable for pond size (farming level) (D_2) had negative coefficients but were not significant. The positive sign suggests that an increase in the use of these input factors would increase production, and a negative sign implies that an increase in these input factors would decrease production.

Table 4. Maximum-likelihood estimates of the SPF and inefficiency function.

Variable	Parameter	Coefficient	t-ratio
Production frontier			
Constant	β_0	4.832***	3.835
$X_{Fingerlings}$	β_1	0.214*	1.657
X_{Feed}	β_2	0.055	0.362
$D_{1(commercial\ feed)}$	β_3	0.104***	2.923
X_{Labour}	β_4	-0.032	-0.231
X_{Manure}	β_5	0.051	0.996
$X_{Pond\ size}$	β_6	-0.025	-0.109
$D_{2(farming\ level)}$	β_7	-1.094	-0.159
Inefficiency function			
Constant	δ_0	0.434	0.474
Z_{Age}	δ_1	-0.005	-0.319
$Z_{Education\ level}$	δ_2	-0.022	-0.597
$Z_{Club\ membership}$	δ_3	2.020*	1.668
$Z_{Extension\ service}$	δ_4	-0.300	-0.644
$Z_{Experience}$	δ_5	-0.001	-0.056
$Z_{Training}$	δ_6	-0.457	-0.770
$Z_{Credit\ access}$	δ_7	0.036	0.147
$Z_{Market\ access}$	δ_8	0.364	1.113
Variance parameters			
Sigma squared	σ^2	0.386***	5.039
Gamma	Y	0.999***	6014418.2
Log likelihood	--	-84.932	
LR test	--	27.766	
Mean TE		29.3	

Note: Asterisks indicate significance. *** Significant at 1%, ** Significant at 5%, * Significant at 10%

4.7 Technical Inefficiency Analysis

The determinants of technical inefficiency are reported in the middle section of Table 4. The study used inefficiency as the dependent variable; hence, variables with a negative (positive) coefficient sign will have a positive (negative) impact on technical efficiency. The coefficients of farmers' age, education, access to extension services, experience, and training were negative and statistically insignificant. The coefficient of club membership was statistically positive and significant at the 10% level, while market access and access to credit had insignificant positive coefficients.

4.8 Technical Efficiency Distribution

The overall mean technical efficiency of the fish farms was 29.3% (Table *4*). It can be seen from Figure *5* that most farms (89%) had technical efficiency scores below 50%, and approximately 4% of the farmers operated on or very close to the frontier. The results also indicate that the least efficient farm must improve its technical efficiency by 70.7% to attain a mean efficiency score. For a clearer understanding of the distribution of technical efficiency among farmers, the frequency distributions of the estimated efficiency are plainly shown in Table *5*.

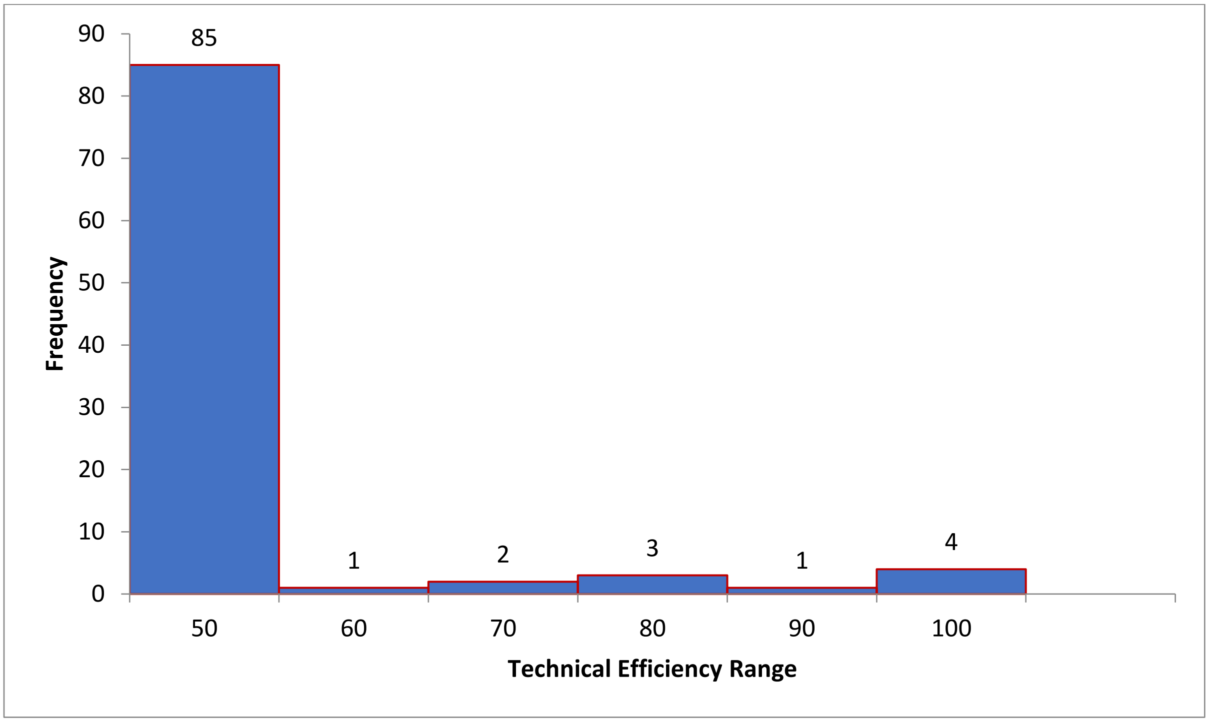

Figure 5. Distribution of the overall technical efficiency of fish farmers.

Table 5. Distribution of the overall technical efficiency of fish farmers.

TE class	**No. of farmers**	**Percentage**
≤ 50	85	88.5
51-60	1	1
61-70	2	2.1
71-80	3	3.1
81-90	1	1
91-100	4	4.2

4.9 Economies of Scale

The returns to scale of production technology are of essential interest given their implications for potential changes in the targeted size of future production units (Kurbis, 2000). This analysis indicates that the fish production function representing aquaculture in Northern Malawi has an elasticity return to scale of 0.26 ($\varepsilon = \sum \beta i$) (Table *4*). Because the estimate is less than one (1), aquaculture production in the region exhibits decreasing returns to scale.

5 DISCUSSION

Results of the Cobb-Douglas model indicate that with a positive sign in most coefficients, *ceteris paribus,* an increase in a particular input will result in an increase in yield. The elasticity of fingerlings was statistically significant at 10% (0.214). This implies that as the stocking density increase by 10%, fish yield will increase by 2%. This is in conformity with a report that a 10% increase in stocking density of stripped catfish in Bangladesh would increase fish production by 2.9% (Ali, Rahman, Murshad-e-Jahan, & Dhar, 2018). Crentsil and Ukpong (2014) and Mussa et al. (2019) also reported that the number of fingerlings was a significant input to fish production in the Amansie-West District in Ghana and Central and Southern Malawi, respectively.

Dummy variables were included in the model to assess the sensitivity of fish production to qualitative factors (Kurbis, 2000). The dummy variable for commercially produced floating feeds (D_1) was found to have a statistically significant effect on fish production at 1 % (0.104); hence, for a 10% increase in quality fish feed, production is expected to increase by 1%. In this study, almost 25% of the sampled fish farmers had access to commercially produced feed. Phiri and Yuan (2018) reported a highly statistically significant and positive sign of the feed coefficient, signifying that feed input is crucial to improved tilapia production in Malawi; hence, formulated feed might have the potential to improve fish production.

With respect to labor, pond size, and the dummy variable for pond size ($D_{2:}$ farming level), the elasticity of output was negative and not statistically significant. This suggests that, in this study, labor input resources are over-utilized, as reported by Akanbi (2015), and that smaller ponds are more efficient than larger ponds. Munthali et al. (2022) observed that there is an inverse relationship between farm size and productivity and considering the small-scale nature of fish farming in the study area, the results further support the hypothesis that small farm households in developing countries are “poor but efficient” (Ogunmefan, 2018).

The five out of eight estimated parameters related to the inefficiency function (i.e., age, education, extension services, experience, and training) have a negative insignificant sign, as expected, because an increase in all these variables should contribute to a reduction in technical inefficiency. Experience in aquaculture farming and increased education, training, and extension services should allow farmers to make better decisions and use inputs more efficiently, thereby reducing the inefficiencies in farming practices. Education can enhance production, in that the higher a farmer´s education, the better he becomes in assessing the importance of new technologies, as well as the efficient use of inputs. In addition, education improves the managerial capacity of farmers, which leads to significantly higher efficiency (Phiri & Yuan, 2018a). It is also believed that farming experience with a higher level of educational achievement may lead to a better assessment of using inputs efficiently and making complex and important decisions in farm investment (Akter, 2010). In this study, the coefficient of education, although insignificant, might have positively influenced technical efficiency.

The insignificant relationship between formal extension services and technical efficiency suggests the need for improved quality of aquaculture knowledge diffusion. Aung et al (2021) indicated that the frequency of extension visits may not matter for improved productivity if the quality of advisory services is poor. This is affirming to the existing literature that contact between extension staff and farmers exposes fish farmers to new innovations and better technologies which results into improved production and productivity due to information flow and enhanced managerial skills (Mussa, Kaunda, Jere, & Ng'ong'ola, 2019).

Among the three other inefficiency parameters, club association, access to credit, and market access all have positive coefficients. Club association was found to have a statistically significant positive impact on technical inefficiency at the 10% level, which agrees with Ogunmafen (2018). This could mean that the farmers clubs are dormant. Club associations generally provide farmers with the opportunity to learn from each other, thereby improving efficiency (Crentsil & Essilfie, 2014). Access to credit is another important institutional factor that can reduce the inefficiency among farmers. Farmers who receive credit are more likely to buy the inputs needed to optimize production potential, including high-quality feed, fingerlings and new equipment (Khan, Begum, Nielsen, & Hoff, 2021; Mussa, Kaunda, Jere, & Ng'ong'ola, 2019), however the findings of this study were not in line with this statement because the credit obtained might not have been invested into the intended purpose of fish production, hence positive and insignificant.

The variation in technical efficiency among farmers ranges from 6% to 99%, with a mean efficiency of 29%, which indicates that farmers in the study area are producing far below the efficiency frontier. However, the output obtained from a combination of inputs used by the farmers could increase their output by 71% through the adoption of technologies and improved best management practices. For this to happen, it would require improving farm-specific factors, thus providing good quality inputs such as feed and fingerlings, training, access, and the frequency of extension visits. This average technical efficiency level is lower than that reported by Phiri and Yuan (2018) for medium-scale fish farmers in Malawi who had a mean technical efficiency of 47%. Mussa et al (2019) also reported a higher mean technical efficiency of 66% for tilapia producers in Central and Southern Malawi. Generally, 88.5% of the farmers in the northern districts of Malawi are in the lower band of the index, with an efficiency of 50% and below, which implies that most farmers have relatively low technical efficiency. Eleven % of farmers with technical efficiencies above 50% used commercial floating feed, indicating that access to commercial feed can improve fish productivity.

The elasticity of scale of the technology is of intrinsic interest, given its implications for potential changes in the targeted size of future production units. This analysis indicates that the returns to scale of Northern Malawi fish farmers is 0.26, representing decreasing returns to scale, which means that an increase in inputs will more than proportionately decrease the output. This signifies low fish productivity in relation to farm size, which may be due to limited managerial skills. The study results agree with those of Mussa et al. (2019), who found that, on average, tilapia production in Malawi is carried out under decreasing returns to scale. A study of small-scale fish farmers in Honduras also reported decreasing returns to scale (Kurbis, 2000), but constructing a confidence interval showed that both increasing and decreasing returns were possible.

6 POLICY IMPLICATION AND IMPLEMENTATION

The findings of this study provide important policy recommendations from various perspectives. Feed is a major component of fish farming, and the availability of high-quality feed and the amount applied by farmers are essential factors for optimal and vigorous fish growth. To achieve the purpose of increased fish productivity in small-scale aquaculture in Malawi, the government and research institutions should be encouraged to develop a proper fish feeding formula with good feeding practices that correspond to the stage of fish growth, culture system, and species types to improve the current use of feed, which is the major input in fish production and constitutes over half of the production costs.

Farmers need to be encouraged to learn low-cost feed formulations to maximize production and profits. In addition, policymakers need to facilitate the development of quality fish feed-producing industries within the country so that farmers can access good quality feed.

As an immediate countermeasure to ensure that the current imported formulated feed is available and easily accessed, the government should facilitate a policy of cost reduction in terms of the cost of inputs, such as the provision of subsidies for the current imported commercial fish feed. Similarly, the government needs to ensure that farmers have access to good-quality fingerlings by establishing fish breeding centers within each district in Malawi. The government must ensure that support services, such as the availability of high-quality input suppliers, which are feed and fingerlings, are readily available to fish farmers.

Furthermore, developmental organizations should promote the dissemination and adoption of the best management practices through quality and effective extension services and provide incentives to small-scale fish farmers to improve the productivity and efficiency of fish farms. There is also a need to invest in and improve the quality of extension services delivery to equip farmers with the skills required to implement the practices properly. Extension services play a crucial role by expanding farmers' access to information and improving their skills, thereby increasing the likelihood of adopting technology and raising farm productivity. Extension efforts to improve yield should focus on the inputs of feed and fingerlings, which were found to be statistically significant inputs to fish production. Likewise, fish farmers should be provided with the services of well-trained extension workers to guide them appropriately on best production practices to enable farmers to improve fish productivity.

Training in technical knowledge for aquaculture production has a positive effect on fish productivity. Thus, policies should focus on improving farmers' management skills and efficiency through better training in production systems and ensuring that all farms have access to other types of formal training.

7 CONCLUSION

This study examined the potential inherent in aquaculture production by measuring the technical efficiency of fish farms. In this study, the "productivity analysis of pond aquaculture in Northern Malawi" revealed that 89% of farmers were technically inefficient, with an average technical efficiency of 29%. Hence, they have 71% room on average, within which they can improve productivity. The significant positive constant coefficient in the efficiency function and the insignificant positive coefficient of the inefficiency function show that there are efficiency capability effects on improving fish productivity in Northern Malawi. The returns to scale show that the average production is carried out under decreasing returns to scale. It is therefore suggested that policy variables such as feed, fingerlings, extension services, and training are identified as important determinants of the technical efficiency of fish farms and should be taken as variables of policy concern for sustainable fish production in Malawi.

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APPENDIX

QUESTIONNAIRE

NAME OF INTERVIEWER…………………………………………………….
DATE……………………………….

Name of respondent…………………………………………………….

1. DEMOGRAPHIC CHARACTERISTICS OF HOUSEHOLD

a) Gender of household head (1=men, 0=women) ………………………………………….

b) Age of household (years)………………………………………………………………

c) Educational level of household members (years)………………………….

d) Are you in a fish farmers association/club (1=yes, 0=no) …………………………………

e) Do you have access to fisheries extension services (1=yes, 0=no) ………………………

f) Do you have access to credit facilities (1=yes, 0=no) ……………………………………

g) Fish farming experience (years)……………………………………………………….

h) Any training in fish farming (1=yes, 0=no) ………………………………………………

i) What is your total household expenditure per year (MK)…………………………………

2. AQUACULTURE PRODUCTION CHARACTERISTICS

a) Number of ponds and area/pond (1,2,3…) …………………………………………

b) Pond depth (m) ………………………………………………………………….

b) Total Pond area (m^2) ………………………………………………………………

c) Number of fingerlings stocked (pieces)……………………………………………

d) Price and total cost of fingerlings (MK)…………………………………………….

e) Source of fingerlings (1=certified producer (government stations), 0=others……………

f) Pond culture system (1=polyculture, 0=monoculture) …………………………………

g) Total fish feed used per production cycle (kg)…………………………………………

h) Price of fish feed per/kg (MK)………………………………………………………

i) Source of fish feed (local-production or commercial) ……………………………………

j) Total fertilizer/manure used per production cycle (kg)…………………………………

k) Price of fertilizer/manure per kg (MK)…………………………………………………

l) Total labor use (person-day) per household per production cycle………………

m) Total labor wages per production cycle (MK)……………………………………………

n) Total fish harvested per production cycle (kg)……………………………………………

o) Total revenue from fish sales per production cycle (MK)………………………………

p) Do you have access of your fish products to market (1=yes, 0=no) ………………………

q) Do you practice Integrated fish farming (1=yes, 0=no) ……………………………………

r) Any climatic change impact affecting fish farming in previous cycle (1=yes, 0=no) ……

s) Do you have any mitigation measures against impact of climatic change (yes=1, no=0)

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