JIMMA UNIVERSITY

COLLEGE OF NATURAL SCIENCE

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF BIOLOGY

Pond Aquaculture Booming, Physico-Chemical Characteristics, Socio-Economic Contribution and Determinant Factors in Some Selected Districts of Jimma Zone, Southwest Ethiopia

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A Thesis Submitted to Department of Biology, College of Natural Science, Jimma University in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Sciences in Biology (Aquaculture and Fisheries Management)

July, 2024

Jimma, Ethiopia

ABSTRACT

Pond aquaculture plays a vital role in global development, driven by the increasing demand for fish protein. Cross-sectional study was conducted to assess the pond aquaculture booming, physico-chemical characteristics, socio-economic contribution and determinant factors in selected districts of Jimma Zone, Southwest Ethiopia. The study districts were selected purposefully based on the presence of aquaculture ponds, with all households owning a fish pond participating. Descriptive statistics was used for data analysis. The findings revealed a total of 146 fish ponds constructed among which 120, 14, 10, and 2 were founded in Omo Nada, Shabe-Sombo, Nadhi-Gibe, and Sokoru, respectively. The most common pond dimensions were 4m to 20m in length, 5m to 20 m in width, and 0.68m to 2m in depth, with an average area of 123.295±65.0914m^2*. Water sources used includes streams or rivers (70.5%), spring water (26.7%), ground water (2.1%), and borehole water (0.7%). Nile Tilapia dominated fish species (96.6%), with mixed tilapia-catfish and Labeobarbus up to 1.4%, while 2.1% of the ponds remained unstocked. The stocked fingerlings were taken from research centers (52.7%), neighboring fishponds (36.3%), Gilgel Gibe reservoir (6.2%), and rivers (2.7%). Physico-chemical characteristics of water include mean values of 24.44±2.22C*^{0} *(water temperature), 5.98±1.41 (DO in mg/l), 7.31±0.71 (pH), 96.16±44.59 (EC in µs/cm), 65.94±0.16 (TDS in mg/l), and 10.85±3.13 (turbidity in inches). A total of 64 specimens of Nile Tilapia harvested from 57 fishponds measured and the mean in total length (TL) from 10.01±1.3 cm to 31.87±0.4 cm and the mean weight range from 13.08±1.3 g to 189.15±8.7g were recorded. Most of respondents had not harvested any fish, and some had sold fingerlings. Key constraints of fish pond farming includes high construction costs, harvesting materials, lack of organized markets, training, predators, and access of feed. The environmental conditions, such as year-round water supply, suitable soil for pond construction, availability of fingerlings in Gilgel Gibe, and farmer interest as major opportunities for the success of the fishpond farm in the study area. In conclusion physicochemical characteristics of the fishpond are favorable for fish production and there are opportunities for further pond aquaculture booming. Therefore managing the constraints and optimizing the construction and productivity of aquaculture ponds for small-holder aquaculture farmers is important.*

Keywords**:** Pond-aquacultures, Physico-Chemical, Socio-Economy, Determinant-factors, Opportunities

ACKNOWLEDGEMENT

First of all, I would like to praise the almighty Allah, whose guidance and provision made this work fruitful. Next, I would like to express my heartfelt gratitude and appreciation to my advisers, Tokuma Negisho (PhD) and Mulugeta Wakjira (PhD), for their general constructive comments and suggestions for the successful completion of my thesis work. May Allah richly reward them for their friendly approach and professional commitment? I express my sincere gratitude to the Jimma University and Nadhi Gibe Administration offices for their financial and material support. The very best thanks and appreciation go to my father, Mr. Abatamam Abagissa, and my astonishing mother, Fatuma Abagaro. Their unwavering love and support have been a constant source of strength throughout my academic journey.

I am especially grateful to my wife, Zinat Abanaga, for her patience and understanding during countless late nights and stressful moments. Her encouragement and love have been invaluable. To my precious children, Mabruk Abdulmajid and Rayan Abdulmajid, thank you for bringing so much joy into my life. Even though they may not understand yet, their smiles and laughter motivated me to keep pushing forward.

Last but not least, among my many best and coolest friends, the ones who encouraged and supported me in whatever resource I needed for the successful completion of my academic career deserve. In addition to this, I want to thank those who supported me in the process of data collection and provided the required data during the study.

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Acronyms

DO	Dissolved Oxygen
EC	Electric Conductivity
ETB	Ethiopian Birr
FGD	Focus Group Discussions
GDP	Gross Domestic Product
NGO	Non-Governmental Organizations
SPSS	Statistical Package for Social Science
TDS	Total Dissolved Salt

1. INTRODUCTION

1.1. Background of the Study

Aquaculture is the fastest growing in food producing sector in the world because of the growing need for fish protein, which is currently driven by population increase, higher incomes, and urbanization (Piasecki et al., 2004; FAO, 2017; Naylor, 2016). It is one of the fastest growing food sectors in the world, which almost contributes to 50% of total fish consumption per capita (Poonkodi, 2014). Fish contribute to food security, improve family diets, and make people strong and healthy (Wakjira et al., 2019 & Gobena, 2019). According to FAO (2012), fisheries and aquaculture provide an income source for 55 million people globally, with aquaculture accounting for 12% of global livelihoods.

In developing country, aquaculture is a lucrative activity offering better employment and foreign exchange prospects for a nation (Ginson et al., 2017). More than 200 million Africans, both rural and urban, utilize fish for food (Bene & Heck, 2005). The value added by the sector as a whole in the last decade was estimated at more than US$24 billion, or 1.26 percent of the GDP of all African countries (FAO, 2014). In addition to supplying food, the fishery sector contributes to gross domestic product (GDP), provides livelihoods for fishers and processors, is a source of hard currency, and boosts government revenues through fisheries agreements and taxes (FAO, 2016).

In Ethiopia, fish comes exclusively from inland water bodies including lakes, rivers, streams, reservoirs, and substantial wetlands that are of great socioeconomic, ecological, and scientific importance (Janko, 2013). The country is expected to have 7185 kilometers of shoreline and 8800 km^2 of lotic and lentic water systems, respectively (Greboval et al., 1994). In addition, Ethiopia has many lakes and reservoirs, small water bodies and floodplain areas covering a total surface area of about 14,794 km^2 (Tibebu, 2021). Aquaculture or fishpond development in Ethiopia was started 1955 when ponds were constructed around Bishoftu and Akaki, both located closer to the Capital Addis Ababa, for growth observation (FAO SFE, 2009; Wakjira et al., 2013). However, aquaculture development in the country remains at an infant stage only with some artisanal extensive pond aquaculture systems in small rural areas with pond sizes ranging between 100-300 m^2 (Rothuis et al., 2012). Apart from a few fish ponds, the only aquaculture activities in the country are mainly the culture-based stock enhancement operations. In culture based fisheries new reservoirs constructed for hydropower or irrigation purpose are stocked mainly with fingerlings of Nile tilapia collected from the existing water bodies (Wakjira et al., 2013). In general, the current output is still much below the predicted possible yield, implying the prospect of additional fishery growth (Tesfaye & Wolff, 2014). The right location for the establishment of a fish farm is critical to the success of an aquaculture operation. Ecological, biological, and operational issues, as well as economic and social factors, must all be considered when selecting an ideal aquaculture site (FAO, 2012).

Physicochemical conditions have a very significant impact on the living environment of fish and therefore on fish farming activity (El-Nemaki et al., 2008). The health of these ecosystems depends on their physicochemical characteristics (Niyoyitungiye et al., 2019). Water quality is the main factor that limits the productivity of aquatic ecosystems and the degradation of the water quality can harm aquatic life (El-Nemaki et al., 2008). The different species of fish as a whole have specific needs in terms of the physico-chemical quality of the water too. Subsequently, the physico-chemical parameters are very important because they have a significant effect both on water quality and breeding performance (Mohammad et al., 2016).

In general, the practice of pond fish production in Ethiopia has a century old history, the introduction and promotion of pond fish production culture to smallholder farmers is relatively recent phenomena (Hirpo, 2017). With respect to effort exerted so far in pond fish production promotion in Ethiopia, the participation of smallholders is low. There are no sufficient studies conducted in the context of demographic, socioeconomic and institutional factors that could hinder or expedite the participation of smallholder farmers' in pond fish production. As a result, no information is available in line with such issues, and the determinant factors are not well identified and recognized. This holds true to Southwestern Oromia regional state and study areas where pond fish productions have been introduced to smallholder farmers (Hirpo, 2017).

Jimma is endowed with abundant inland water resources, including rivers, lakes, reservoirs, ponds, and huge floodplain areas. Despite this wealth of resources, the contribution Jimma Zone to national fish production and marketing has been relatively low. Although some pond aquaculture development activities, and the water bodies of the zone are rich with the most diverse fish species, its fish production and marketing are rarely reported. The existing aquaculture activities and, potential development, along with associated challenges, have not been thoroughly assessed and documented. A quantitative assessment of the spatial extent and distribution of aquaculture ponds in the zone is crucial for evaluating development efforts, identifying challenges and opportunities, and designing interventions to ensure the sustainability of the ponds and their associated socioeconomic benefits. Furthermore, it is important to analysis the major factors contributing to the low fish production and assess the orientation of the fish market in the area. Thus, this compressive assessment will provide valuable insights for stakeholders, and local communities to effectively promote and support the growth of aquaculture in the zone.

1.2. Statement of the Problem

Aquaculture is a vital food production technology, particularly in developing nations, playing a crucial role in combating malnutrition and poverty (Rohana, 2011). In Ethiopia, the government recognizes aquaculture's potential to enhance fish production, addressing food security challenges and alleviating poverty (Natea, 2019). With proper support and investment, aquaculture can significantly contribute to food security, poverty alleviation, and economic development (FAO, 2018). Fisheries and aquaculture continue to provide essential food, nutrition, income, and livelihoods for millions globally (FAO, 2016).

Jimma Zone, located in the southern Oromia regional state, is identified as having high potential for fish production (Wakjira et al., 2013). This makes it an ideal area to develop pond aquaculture, which could significantly benefit the national economy and the livelihoods of people living near rivers and reservoirs (SELF, 2018). However, despite these opportunities, smallholder farmers' participation in pond fish production remains low. While previous studies have explored fish production and reproduction in Ethiopia (Tibabu, 2021 & Natea et al., 2017), there is limited research on the status of aquaculture pond development, pond management practices, fingerling sources and stocked species, socio-economic factors influencing pond development, and the reasons behind low participation by smallholder farmers in Jimma Zone. This lack of data hinders our understanding of the factors affecting farmers' involvement in pond fish production. Reports from farmers in Jimma Zone, particularly Shabe Sombo, Sokoru, and Nadhi Gibe, suggest high failure rates in fish production(Personal Communication**)**. Addressing these issues related to pond development, including pond design, accessibility, and the socio-economic characteristics of fish farming in the area, is crucial. Therefore, this study aims to bridge this knowledge gap by assessing the status of pond aquaculture development and investigating the major challenges related to pond aquaculture development activities in selected districts of Jimma zone.

1.3. Research Questions

- What is the status of Pond aquaculture booming in the Jimma Zone?
- Are physicochemical characteristics of the fishpond favorable for fish production in the study area?
- What is socio-economic contribution of pond aquaculture for the farmers?
- What are determinant factors for successful pond aquaculture development in the study area?
- Are there any opportunities that can enable us to optimize the construction and productivity of aquaculture ponds for small-holder aquaculture farmers?

1.4. Objectives

1.4.1. General Objectives

The objective of this study is to assess the status of Aquaculture Booming, Physicochemical Characteristics, Socio-economic Contribution and Determinant Factors in Some Selected Districts of Jimma Zone, Southwest Ethiopia

1.4.2. Specific Objectives

- ✓ To assess the boom of pond aquaculture
- ✓ To analyze physico-chemical characteristics of aquaculture ponds
- ✓ To assess socio-economic contribution of pond aquaculture
- ✓ To identify determinant factors for successful pond aquaculture

1.5. Significance of the Study

This study holds significant value for improving pond aquaculture in the Jimma zone. By identifying key factors affecting success, the research provides a roadmap for future initiatives. This knowledge can empower small-scale fish farmers to make informed decisions regarding pond design, fish species selection, and overall management practices. This, in turn, can lead to increased yields and profitability, contributing to the economic well-being of communities.

Furthermore, the study sheds light on critical challenges faced by the local aquaculture sector, such as water quality issues, infrastructure limitations, and access to quality fish stock.

Highlighting these constraints can raise awareness among policymakers, researchers, and stakeholders. This increased visibility can attract investments and targeted interventions to address these challenges, fostering the sustainable growth of pond aquaculture in the Jimma zone. Ultimately, the study's findings can contribute to food security and economic development in the region. Additionally, the research serves as a springboard for further investigation. By understanding the specific requirements of small-scale fish farmers in the Jimma zone, future studies can delve deeper into areas like economic viability and best practices for overcoming identified constraints.

2. REVIEW OF RELATED LITERATURE

2.1. Global Overview of Fish Production and Consumption

By any measure, fishes are among the world's most important natural resources. Global production of fish from capture of fisheries and aquaculture and the food fish supply is currently at the highest on record and remains very significant for global food security, providing more than 19 percent of total animal protein supply (FAO, 2016). Aquaculture has the potential to reduce hunger and poverty while improving human health and well-being (FAO, 2020). Freshwater fish account for about 75% of the global edible aquaculture volume (Naylor et al., 2021). Over the last two decades, global aquaculture development has steadily increased while wild aquatic catches have stagnated (FAO, 2020; Naylor et al., 2021; Garlock et al., 2020), calling for increased aquaculture development in different parts of the world to cover the deficit.

Aquaculture in Africa is still in its early stages and is largely focused on a few nations, although it already generates about $3 billion per year (FAO, 2014). More than 200 million Africans, both rural and urban, eat fish (Béné & Heck, 2005). The value generated by the sector as a whole during the last decade was projected to be more than US$24 billion, or 1.26 percent of the GDP of all African countries (FAO, 2014). In addition to supplying food, the fishing sector adds to GDP, provides employment for fishermen and processors, and is a source of hard currency through fisheries agreements and taxes (FAO, 2016).

2.2. Status of Fisheries Production in Ethiopia

Ethiopia is endowed with several water bodies (lakes, rivers, streams, reservoirs, and substantial wetlands), consequently it contains a high diversity of Ichthyologic (Desalegn & Shitaw, 2021). The total surface area of lentic water bodies in Ethiopia is approximately 8,800 km^2 (Grebovai et al., 1994), with major rivers totaling nearly 7,400 km in length (Desalegn & Shitaw, 2021). Nearly 200 fish species live in these bodies of water (Golbtsov & Darkov, 2004). According to these sources, Ethiopia produces 51,500 tons of fish per year, but only 30–38% of it is used (Tesfahun, 2018).

Ethiopia´s fishery is entirely inland and also artisanal, with landings made at many dispersed sites where records are not kept very well. In 2010, total production was 18058 tons valued at approximately USD 600,000 (CSA, 2012). According to the 2010 Central Statistics Agency (CSA) report, export quantity amounted to 849 tons, while import quantity amounted to 421 tons. The fisheries sector provides regular employment for 21 thousand poor people and seasonal or part-time employment for many more. The primary sector employs an estimated 13,200 people, of whom 4052 are full-time fishermen, and the secondary sector is believed to employ an estimated another 20,000 people (CSA, 2012). This work is closely linked to other activities such as farming, livestock rearing, and fuel wood collection. Ethiopia's water bodies support a diverse aquatic life, including more than 180 fish species, of which about 40 are endemic. Many artificial water bodies are also stocked with fish for fishing. Overall authorities prioritizing other sectors result in uneven efforts regarding management and data collection on fisheries in Ethiopia (Aragaw, 2011).

The empirical model suggests that current total fish production potential is around 50 000 tons annually, though assessments in the mid-1990s, when landings were less than 10 000 tons, suggested that several lakes were already fully or overexploited. The empirical models generally do not take into account the effect of unsuitable management or fishing practices and have been criticized for consequently grossly overstating the maximum sustainable yield (MSY) (Aragaw, 1998). Even if many local fish species have been identified, the bulk of the production is made of Tilapia, Nile Perch, Barbus, Bagrus, and Catfish. Tilapias are the most popular species contributing to the catch, but nile perch used to contribute the largest part of the catches from Lake Chamo and Abaya (FAO 1995). Based on an empirical model, the overall fish potential yield was estimated at between 40 000 and 50 000 tons per year for the main water bodies (FAO 1993). Despite this potential, the Ethiopian fishery is poorly developed and has a marginal contribution to the country´s GDP. In Ethiopia, people consume a lot of fish, especially in the production areas, big cities, and towns like Ziway, Bahirdar, Addis Ababa, and Arbaminch. Outside of these areas, the consumption of fish is extremely low for a variety of reasons, including a lack of integration of fish into the population's diet, a lack of a culture of small-scale fish farming, religious influences on consumption patterns, a limited supply of the product, and high prices (Janko, 2014).

Table 1: Fish production potential estimates of different water bodies in Ethiopia

Water bodies type	Area (km^2)	Length (km)	Fish potential yield (tone/year)	Mean (tone/year)
Major lakes	7,740		37,346-41,177	39,262
Major reservoirs and dams	1,447		7,698-8,059	7,879
Small water bodies	4,450		25,678-26,314	25,996
Rivers		8,065	18,855-23,954	21,405
Total	13,637	8,065	89,577-99,504	94,541

Source: (Tesfeye & Wof, 2014).

Despite the fact that Ethiopia's entire potential yield of fish is large, actual fishing productivity is substantially behind predictions. This could be because of a number of things. The main causes of fish stock depletion in freshwater fish are a lack of technologies capable of resolving fisheries production problems (Tesfeye & Wof, 2014), habitat degradation, and destruction, and this is why fish populations differ per water body, even from habitat to habitat (Vijverberg et al., 2012).

2.3. Factors Affect Pond Aquaculture Development

2.3.1. Soil Characteristics

A field assessment to identify the surface and subsurface soil characteristics at the site should be conducted as soon as possible. Clays and silty clays are suitable for this function; sandy and gravelly clays are typically enough. The suitability of a pond location is also determined by the ability of the soils in the pond region to store water (Boyd & Tucker, 1998). Clay levels of 15 to 20% are ideal, but soils with 5 to 10% clay can be used if carefully graded. Sands with a coarse texture and sand-gravel mixes are not suited. Texture is determined by the size, shape, and distribution of soil particles (Avery, 2010). Soils have qualities that can be determined by sight and feel, according to Kovari (1984). Ponds built on unsuitable soils will experience dike erosion and excessive seepage, requiring the use of additional water to compensate for losses (Wakjira et al., 2019).

2.3.2. Topography

Topography refers to the area's surface features, and it is crucial for both construction and future maintenance. Elevation and slope of the land are very critical in selecting an appropriate site for aquaculture development. Poor drainage and thus high risk flood zones are to be avoided, while land with moderate elevations and no more than a gentle slope is preferred (Wakjira et al., 2019). One goal of site selection is to gather as much water as possible with as little soil movement as possible. In very flat areas (less than 1% slope), the pond bottom may be lower than the original ground level, preventing the pond from emptying completely. Earth-moving costs can be decreased, and ponds can be drained utilizing gravity flow in locations with typical slopes of 2 to 5%. Building of levee ponds on low-gradient slope sites typically requires the movement of around 1,100 to 1,200 cubic yards of earth per acre (2,078 to 2,266 m^3/ha), while the actual amount of material moved varies (Gebrekirstos & Gebreegziabher, 2019).

2.3.3. Pond Site Selection and Construction

The success or failure of an aquaculture system is dependent on many factors including the selection of a suitable site and the design and construction of facilities that enable efficient and economic operation (Wurts, 1992). While creating a fish farm, good access to the potential farm site, distance from water sources and the landowner's house are all crucial considerations to take into account (Wakjira et al., 2019). According to Asmare et al. (2019), farmers begin pond construction without first considering the viability of the location for pond construction or its potential as a water source. During pond construction, site selection and inlet/outlet-related concerns are among the serious issues that significantly impact pond performance. Pond aquaculture requires the location of aquaculture ponds to be chosen based on their physical and potential appropriateness for pond fish farming (Ssekyanzi et al., 2022)

2.3.4. Size and Shapes of the Ponds

The size of the pond that can be developed is normally determined by the topography. Ponds larger than 20 hectares are difficult to manage and should be avoided. Locations where very large individual ponds could be developed can be grouped into smaller ponds built in series. Size is also determined by marketing strategy; processors and custom harvesters prefer not to catch fish from ponds smaller than 5 acres. Ponds smaller than 5 acres may be viable if local markets are intended for weekly sales (Singh et al., 2004).

2.3.5. Drains and Pond Bottoms

Drain pipes should be installed at the pond's lowest point. Drains should be designed such that ponds can be drained within a few days of opening the valve. To keep fish from escaping, a barrier should be placed at the drain's opening. To assist sieving, all trees, tree roots, stones, and other waste should be removed from the pond bottom. The pond bottom should be flat and slightly sloped to the drain so that all of the water drains. Digging "harvest" basins should not be built in watershed catfish ponds because they add extra complexity. For reduced aquatic weed growth and to allow for greater fish utilization, all portions of the pond should be 2.5 to 3 feet deep. Shallow necks at the top should be removed to prevent oxygen-depleted fish from coming together there (Jimmy & Avery, 2010).

2.3.6. Stocking Density

Stocking density is a critical parameter in fish culture operations because it directly affects fish growth and survival. Fish growth rates accelerate as stocking densities fall, and vice versa. There is more space, food, and dissolved oxygen in a pond with fewer fish per unit area (Hassan, 2010). To target large-scale fish with a high unit value and total biomass, large farms typically stock at low density (0.11 fish/m2) with a high feeding rate and a longer production cycle. Because of resource constraints, small farms have a more short-term strategy. They tend to stock large-sized fingerlings at a higher density (0.47fish/m2) with less feed for a quick harvest (Belton et al., 2017).

2.3.7. Feeding Frequency

The feeding frequency is the number of times fish in a pond are fed in a day, and proper feeding frequencies reduce starvation and result in more uniform fish size. Feed is the most expensive operating cost in fish farming, optimal feeding frequency, according to Mollah (1982), may provide maximum utilization of the diet. The types of food, rate, feeding frequency, food intake, and ability to absorb nutrients all have a large impact on fish growth at all stages. Among these, feeding frequency is critical for early fish survival and growth. Overfeeding not only reduces feed conversion efficiency and increases input costs, but it also causes waste accumulation, which has a negative impact on water quality (Biswas, 2006).

2.4. Physico-Chemical Characteristics of Pond Aquacultures

The most significant criterion to consider while deciding on the suitability of a fish pond location is a secure water supply of sufficient quantity and adequate quality (Kovari, 1984). Feeding rates, frequency, and feed type have been shown to influence water quality (dissolved oxygen, alkalinity, turbidity, ammonia, and nitrate) levels in ponds, especially when dietary protein levels are increased (Singh et al., 2004). However, the quality of water in fish farming facilities is not continuous but rather dynamic. Physicochemical characteristics such as dissolved oxygen (DO), pH, carbon dioxide, total ammonia nitrogen (TAN), temperature, turbidity, hardness, and salinity change regularly based on cultivation conditions and the environment (Boyd, 2020). Weather, stocking density, time of day (sunlight), primary production (phytoplankton density and species composition), feed quality, cultured fish species, organic matter concentration, upstream activities, and the source of culture water itself all influence this. In the other study, the physical and chemical properties of water were similarly essential because fish are completely dependent on water to breathe, feed, develop, excrete waste, maintain a salt balance, and reproduce. In order to maintain good water quality, it needs to locate fish farms away from pollution and other water uses that could undermine water quality. The most important physico-chemical water quality characteristics for successful fish aquaculture include water temperature, dissolved oxygen, pH, electrical conductivity, and turbidity (Wakjira et al., 2019).

There are six categories of water sources being used for pond production, which include springs, wells, rivers, streams, or lakes; surface runoff; ground water; and municipal. When choosing a good water source, it will be helpful to know what characteristics characterize an "ideal" source and how the source can be affected in the future. First, the source must be uncontaminated by excessive nutrients, chemicals, or heavy metals. A source meeting this criterion should be further investigated to determine the threat of future contamination. The second criterion of an "ideal" source is the availability of the large volumes of water necessary for commercial fish farms. For example, the volume of water available can decrease after extensive timber harvests within the source's watershed (Swann, 1993).

2.4.1. Pond Fertilizer

Fertilization of aquaculture ponds increases phytoplankton productivity, which is the food source for zooplankton and benthic animals (Mischke, 2012). Both organic and commercial fertilizers can increase phytoplankton production and enhance aquaculture production in ponds (Boyd, 2018). Aquaculture pond fertilization is analogous to pasture fertilization to increase forage for livestock. Livestock manure, plant crop residues, food processing wastes, fresh-cut or dried grass, and certain chemical compounds are examples of aquaculture fertilizers. Water quality deteriorates as nutrient input increases, which stresses farm animals and increases the likelihood of disease. As a result, the amount of production possible in fertilized ponds is limited, and maximum production rarely equals optimum production (Boyd, 1998). Excessive inputs of fertilizer should be avoided because they can result in dense phytoplankton blooms that cause dangerously low dissolved oxygen concentrations during the night, after certain weather events, and following phytoplankton die-offs. Excessive inputs of manure can also cause dissolved oxygen depletion as a result of the oxygen demand to decompose the manure (Boyd, 1975).

2.4.2. Lime

The reason for liming aquaculture ponds is to neutralize soil acidity and increase total alkalinity and total hardness concentrations in the water. This can enhance conditions for the productivity of food organisms and increase aquatic animal production. Freshwater ponds with less than 40 or 50 mg l-1 total alkalinity, brackish water ponds with total alkalinity below 60 mg l-1, and any pond with a soil pH below 7 usually will benefit from liming (Boyd and Tucker, 1998). Alkalinity concentrations below 20 mg/L frequently cause large imbalances in daily pH values, putting aquatic animals under stress (Wurts, 2004).

2.5. Length Weight Relationship of Fish Species

The studies on the length-weight relationship are very important for fishery biology and stock assessment of fishery resources. Generally, the growth of fish is the most suitable feature to establish population analysis, typically indicated by variations in length and weight (Mansor et al., 2010). Investigations on the length-weight relationship and condition factor enable us to compare the populations of the same species in different localities. The relationship also gives an idea of the condition of fish associated with maturity and breeding (Nan Zhang, 2016). The length-weight relation equation provides a mathematical relationship among the two variables, length and weight, so that the unknown variable can be easily calculated from the known variable. It is also used to find out the expected weight from length and weight and is used as an indication of fatness. These expressions are helpful for creating yield equations and estimating the strength of the population. The precise relationship between length and weight differs among species of fish according to their innate body shape and within species according to the condition of individual fish (James et al., 2000; Nan Zhang, 2016).

The length-weight relationship may vary over time due to some internal and external factors. The factors influencing the variation in length, weight, and condition of fish may be due to food availability, sex, maturation, spawning seasons, and water conditions. Moreover, LWR provides information on the condition and growth patterns of fish (Keri et al., 2011). Length-weight relationships are often used as an indication of the gonad development of fish and are used for knowing the life history traits of different species (Ayoade & Ikulala, 2007). The growth of fish can be categorized into three categories: isometric growth, negative allometric growth, and positive allometric growth. Whereas the fish shows an isometric growth pattern, there is no change in body shape or weight according to the increase in length. A fish in good condition exhibits isometric growth. While the lean fish show negative isometric growth. Insufficient availability of food and environmental changes are the major reasons for negative allometry in fish. When a fish is showing positive allometric growth, it increases in weight at a faster rate in relation to its length. Fat fish exhibit positive allometric growth. An increase in the ovary during breeding season increases the total body weight of a fish. Hence, the length-weight relationship is an indication of gonad development in fish (Shabir et al., 2012; Arida et al., 2013; Xiong et al., 2016).

2.6. Socio-Economic Importance of Fish Production in Ethiopia

Food security, poverty alleviation, and economic growth all rely on sustainable fisheries management. Fisheries are thus recognised as an essential strategy in the fight against poverty. It contributes to Ethiopia's economic progress. Ethiopia realised around USD 14,000,000 from its capture fisheries in 2010, while the fishery sector positively impacted 40,000 livelihoods in the same year (Assefa, 2014). Fish is essential in both domestic trade and the import and export sectors. The country imports a substantial amount of fish from adjacent countries, while some of these shipments are transported to Sudan across the porous border with neighboring South Sudan. The per capita fish supply is roughly 200 g, which is much less than the East African subregion's average of 2.6 kg per capita per year (FAO, 2015).

Although most fish sellers do not have access to basic cold chains with ice and insulated containers, Ethiopian fisheries do have a few basic fish handling and preservation institutions with electricity and freshwater supply. As a result, many people work in this area as a source of income. Fresh fish storage often lasts only two days due to a pervasive shortage of basic cold chains. As a result, fish marketers focus their efforts during religious fasting seasons, when demand is higher (Ann et al., 2013). Consumption of fish has several health, nutritional, environmental, and social advantages over other terrestrial animal meats. Even when consumed in small quantities, fish often comprises an important nutritional part of many people's diets in developing countries. It is an important source of protein and minerals, and it increases the quality of protein in primarily vegetable and starch-based diets by delivering necessary amino acids. Fish contains minerals and micronutrients that are crucial for cognitive and physical development, especially in children, and is an important part of a balanced diet. Fish is the primary source of sustenance in some of the world's poorest countries, producing an increasing demand for this staple. As a result, fisheries are seen as an essential sector in the quest to enhance animal protein intake and attain food security for the expanding population (FAO, 2014).

Employment in the fishing sector has grown more rapidly than both the world population and employment in agriculture. A considerable workforce is employed, both directly and indirectly, by Ethiopia's capture fisheries, which also help sustain local communities. While the sector directly employed 4052 people in 2010, it also employed 9148 others through indirect employment. Therefore, the sector is a good means of creating job opportunities for rural, pre-urban, and urban unemployed and underemployed people. This is especially so around the Great Rift Valley and areas surrounding the lakes, reservoirs, rivers, and other small water bodies with major fishing activities (Alazar, 2016). The economic activities of fishers and their related activities help the rural areas of Ethiopia where significant fishing occurs. In those areas, much more than in the urban and per-urban centers, fisheries are increasingly recognized as an alternative means of addressing the problems of food security and poverty, which is consistent with the rural development objectives of the sector. There is a national awareness that rural areas and the agricultural sector, which support more than 80 percent of the total population, are the basis for bringing about rapid and equitable economic growth and development in the country (FAO, 2014).

2.7. Challenges to Fish Production

Like other African countries, Ethiopia is challenged by different events that pose serious constraints for overall fish development and the fishery production system. There are many rivers and lakes available in Ethiopia that is used for fish production, but there is still a problem regarding fish production and productivity to increase private profits and the GDP of the country (Kebede et al., 2017). The low level of fish production may be attributed to the traditional fishing methods and equipment being utilized by the fishermen. Anthropogenic activities are causing the major conservation challenges of fish and fisheries in Ethiopian water bodies: illegal fishing activities such as using narrow mesh-size nets and poisonous plant seeds that are toxic to the fish; a lack of community awareness in fisheries management; limited institutional, technical, and financial capacity; low research and development capacities; overfishing; wetland degradation; dam construction; deforestation and expansion (Assefa & Kelemework, 2013).

Historically, eliminates have been motivated by economic reasons: many species and sizes have limited market acceptability; they have no or low commercial value; but also, in a system of limited landings by stock, fishers have traditionally discarded the smaller, lower-value fish to maximize the value of the fish landed and counted against quotas, a practice known as "high grading." Certain customer satisfaction provisions, however, have traditionally made discarding mandatory, namely for (a) catches over quota, (b) catches of undersized fish, and (c) catches that did not correspond to the expected catch composition of the legal mesh size (Uhlmann et al., 2019). According to the review by Suuronen and Bartley (2014), lack of investment in post-harvest infrastructure often leads to low quality and, hence, low value of fish and fish products. The problems may arise due to poor awareness of the length of first sexual maturity among fishermen. According to Muluye et al. (2016), the majority (50.6%) of the fishermen did not know whether the catch was mature or immature, as documented in Lake Hawassa. Only a few fishermen (1.3%) know the correct length at the first sexual maturity of a fish. In addition to this, inefficient fishing gear, a lack of motorized boat service, poor transportation access, a lack of value-adding facilities, a lack of fish handling facilities (like refrigerators), poor postharvest handling, and gear theft are the main constraints to fish production in different regions of Ethiopia (Abelti et al., 2014). In general, the Ethiopian fishery is under several constraints due to different challenges (Kebede et al., 2017).

2.8. Opportunities and Future Perspectives of Fish Production in Ethiopia

According to Garcia and Cochrane's (2005) global evaluation, raising fish in pond aquaculture in Ethiopia is still in its early phases of application, while it may be highly advanced in a few countries. It is the sole opportunity for fisheries to become responsible and sustainable, but its implementation poses numerous obstacles for stakeholders. According to the review of Abraham and Mitiku (2018) the future fishing villages' offers homogeneous and less dispersed pastoral communities which are ideal for social mobilization for poverty alleviation programs However, Reservoir fisheries require minimal initial investment and provides quick returns compared to other economic activities. Access to microfinance facilities, which have received strong internal and external support, will therefore promote rapid development of fisheries, especially for the benefit of women and youth. It does not also require sophisticated skills and knowledge for the entry and coping up with operation at small scale level (Mitiku, 2018).

The study done by Askale and Tegegn (2019) concluded there are no seasonal and religious effects on fish consumption patterns and availability of water through the year, and the mentioned opportunities may increase the income of fishermen when they put an emphasis on improving productivity. Increasing the number of fishermen to exploit the fish potential of the reservoir is important to increase society's income. Attractive fish prices at the local market for better profit, the presence of diversified fish species, and the inhabitants' traditional knowledge of fisheries and good consumption habits are considered occasions for the sector's escalation. In addition, the availability of gotera (or kefo), a locally made fishing gear that has a hive-like structure, is the best practice for catching fish. Because fishermen let small fishes out into the water while they are collecting their catches. This system enables fishers to be selective or non-selective, which depends on the size and preference of the fishers. Fishermen have a good practice in post-harvest processing, which is either fresh or gutted when there is a demand for fish or sun-dried during a production surplus (FAO, 2018).

The regional pastoral extension program can rigorously conduct an extension service and provide training to the communities. Not only this, while the supply from capture fisheries is lagging behind, the demand for fish is growing in Ethiopia, which offers opportunities for aquaculture businesses to play a role in improving fish production and expanding the fish market opportunities. Much land is suitable for aquaculture in Ethiopia and for most systems (earthen pond, concrete pond, cage in lake, and more). The absence of social and cultural taboos on fish consumption is also another asset for fish production in Ethiopia (Erkie et al., 2016).

3. MATERIALS AND METHODS

3.1. Description of the Study area

The current research was carried out in the Jimma Zone between January 2023 and June 2024. This study was conducted in selected districts of Jimma Zone (Omo Nada, Sokoru, Shabe Sombo, and Nadhi Gibe) in Oromia Regional State. Jimma Zone is located in Oromia regional state, 356 kilometers south-west of Addis Ababa, at a longitude of 35° 52'–37° 37' E and a latitude of 7° 36'–8° 56' N (Endalew et al,.2020). The map of the study area is shown on figure 1.

Omo Nada: The district lies between 7° 17" to 7° 49" North latitudes and 37° 00" to 37° 28" East longitudes (Engdawork, 2015). It is located at a distance of 295 km from Addis Ababa and 71 km from Jimma, Ethiopia. The district is bordered on the west by Omo Beyem, on the north by Sokoru, on the south by Kersa, and on the east by Nadhi gibe (Engdawork, 2015). The research area's altitude spans from 1000 to 3340 meters above sea level. According to the land survey report, over 56.8% of the land is arable, 25.2% is pasture, 6.3% is forest, and the remaining 11.7% is swampy and degraded land. The district is classified into three types: Dega (12%), Woinadega (63%), and Kolla (25%). The study features three significant rivers: Gilgel Gibe, Nada Guda, and Beyem, with an average rainfall of 1467 mm (Endriyas et al., 2018). The annual rainfall ranges from 1066 to 1200 mm, with a mean annual temperature ranging from 18°C to 25°C (Engdawork, 2015).

Shabe Sombo: The district shares common boundaries with Saka Chokorsa in the north and north-east, SNNP regional state in the south and south-west, and Gera in the west. The district is located between 1200 and 2440 meters above sea level. The territory is divided into two agroclimatic zones: Winadega and Dega, and the average annual minimum and maximum temperatures were 70 and 300 degrees Celsius, respectively.

Nadhi Gibe: Nadhi Gibe (Tiro Afeta) is located in the eastern central part of Jimma Zone, 64 kilometers from Jimma town in Oromia regional state and 316 kilometers south-west of Addis Ababa at longitudes of 35° 52'–37° 37' E and latitudes of 7° 36'–8°. It has a land area of 74.9 km2 and common boundaries with Botor Tolayi, Sekoru, Limu Kossa, Kersa, and Omo Nada districts. Altitudinally, the district lies between 1640 and 2800 meters above sea level. The district is classified into winadega (85%) and dega (15%) agro-climatic zones.

Sokoru: Sokoru has common boundaries with Omo Nada on the south, Tiro Afeta on the west, the southern nation, nationalities' regions on the north and east, and the Gibe River on the north. The altitude of this district ranges from 1160 to 2940 m above sea level.

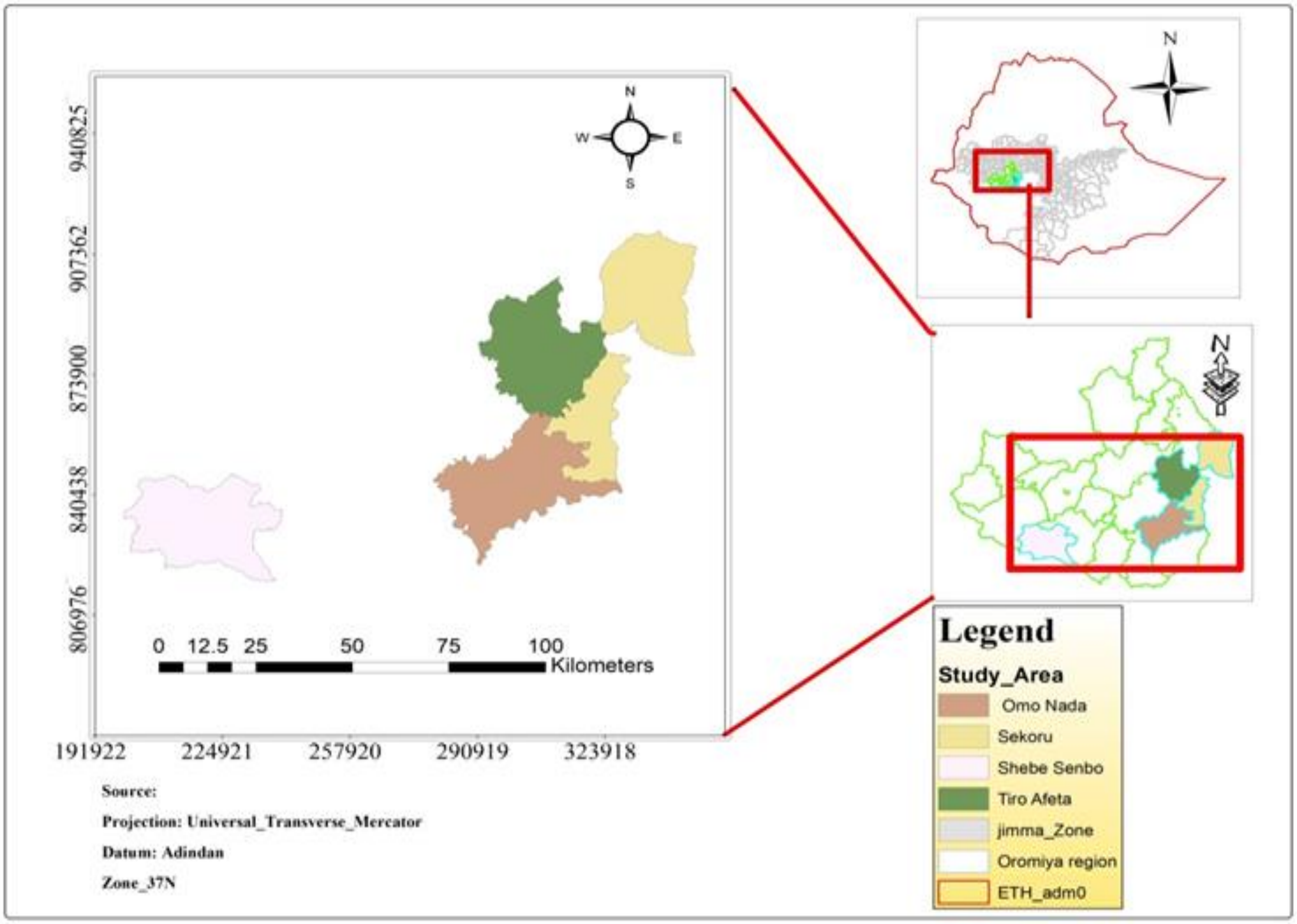

Figure 1: Map of the study area

Source: Ethiopian Atlas drown by Arc Map V.10.1

3.2. Selection of the Study Districts and Study Population

The study districts were purposively selected based on availability of the fishpond and water sources to develop fishpond farm. The main criteria used for site and respondent selection were based on the existence of pond aquaculture and its practices. The study populations were all fishponds available in the study area.

3.3. Study Design and Study Population

Cross sectional study was conducted between January 2023 and June 2024 to assess the pond aquaculture booming, physicochemical characteristics, socio-economic contribution and determinant factors in some selected districts of Jimma Zone, Southwest Ethiopia. The study population was all fishponds available in the study area whether it is functional or nonfunctional. All households who have fishpond were participated in the study.

3.4. Sample Size Determination

Since there were small ponds in the study area, all fishponds available in the study area (146 fishponds) were purposively selected and included in this study. Concerning householders, there were small famers practicing fishpond farm in the study area and so, participants of this study were all smallholder farmers working on fishpond who were purposively selected. Accordingly 108 householders working on fishpond farm were participated in this study.

3.5. Sampling Procedure and Data Collection

The districts were purposefully chosen based on availability of fishpond and every household who own fishpond were participated on the study. The required data were collected by preparing a semi-structured questionnaire, direct observation, focus group discussions (FGD), and key informant interviews. Different semi-structured open and closed ended questioner were prepared in English for both household and FGD. The semi-structured questionnaire were then translated to Afan Oromo and used to collect information about the existing pond aquaculture system, farmers' practices in pond fish farming, and the major challenges for pond aquaculture (Appendix I). During fishpond observation, materials such as electronic balance, measuring board, Adwa pH/ORP/EC/TDS/Temperature Bench Meter (Code AD8000) and Secchi disk were used to record data related with physicochemical characteristics of the pond, weight and length of the fish harvested from the pond. The data from each constructed fish pond was thoroughly collected.

Moreover, qualitative and supplementary data was collected from key informants (including fishery experts) and focus group discussions (FGD). Eleven (11) FGD (6 from Omo Nada, 2 from Shabe SOmbo, 2 from Nadhi Gibe and 1 from Shokoru) with five (5) to seven (7) members were conducted. In order to identify the major constraints that affect pond aquaculture development in the area, the potential constraints were drawn up from FGD and personal observation of each fishpond. Collecting data on constraints was based on major problems farmers complained about during focus group discussions, such as predators, inadequate transport, lack of training, lack of good sources of fingerlings, high construction and production costs, a lack of feed, and a lack of equipment for harvesting. During data collection, respondents were asked to rate the extent of each problem using three scales. Likert scale (severe, low, and not a problem) (Appendix I).

3.4. Weight-Length Measurement of Fish Samples

Fish samples were collected from each functional pond and weight and length were assessed with an electronic balance and measuring board. The total length (cm) of each fish was taken from the tip of the snout (mouth closed) to the extended tip of the caudal fin using a measuring board. Body weight was measured to the nearest gram using a digital balance after removing adhered water and other particles from the surface of the body. For more information, see the detail Fish Length and Weight data with their specific pond and location on Appendix III

3.5. Physico-Chemical Characteristics Measurement

For each functional pond, water temperature, dissolved oxygen, electrical conductivity, and total dissolved salt were measured in situ by using multi-physic parameters (Palintest MICRO 800 England, UK), pH was measured by the Adwa pH/ORP/EC/TDS/Temperature Bench Meter (Code AD8000), and turbidity or secchi depth was measured using a secchi disk.

3.6. Data Analysis

All data were recorded on Microsoft Excel and analyzed by SPSS software (version 23). Descriptive statistics were used to analyze the categorized data on characteristics of fish ponds, risk factors that affect the productivity of fish ponds, major constraints of fish pond farming, and opportunities to develop fish pond farms in the study area. Chi-square was used to test whether influencing factors are significantly affecting the functionality and productivity of fish ponds. The analysis outputs were expressed as the mean plus or minus the standard deviation (M±SD). Qualitative data was used to support the quantitative data. A significant difference was established at $p<0.05$.

4. RESULTS

4.1. Demographic Characteristics of Study Participants

This study was conducted in four districts of Jimma Zone, involving a total of 108 participants, consisting of 94 smallholder farmers and 14 leaders of micro-enterprises from the local communities. Among the total participants, 91 were male and 17 were female, indicating a remarkable gender disparity in fishpond farming participation, with fewer females engaged compared to males. All the participants identified themselves as family heads. The study primarily focused on demographic characteristics such as age, gender, education level, marital status, and household size. The participant's ages ranged from 23 to 82 for both males and females, with a mean age of 42.09±10.06 years, indicating significant youth involvement in the fish farming business. The highest age frequency (58.3%) was observed in the 36- to 50-year-old category for both genders. Regarding family size, the number of people economically supported by the family heads ranged from 1 to 17, with mean of 6.16±3.52. The marital status analysis revealed that 96.3% of fish pond farmers were married, while 3.7% were single. Interims of educational attainment: the majority (50.9%) of fishpond farmers had received non-formal education, followed by 39.8% with primary education, and a minority (7.4%) with secondary to a degree-level education as their highest level of education. A summary of the demographic characteristics of the study participants is presented in Table 2.

Concerning Microenterprises Working on Fishpond Farms, the data obtained from surveys and personal observations indicated the presence of fourteen (14) Microenterprises comprising 111 members, with 79 males and 47 females who collectively owned 29 ponds. Specifically, twenty-seven (27) microenterprises were identified in Omo Nada District, whereas only two were found in Nadhi Gibe District. There were no microenterprises engaged in fish pond farming in both Sokoru and Shabe Sombo Districts. As illustrated in Table3.

Table 2: Demographic characteristics of fishpond farmer

Participant Characteristics	Category	Frequency	%
Age	20 – 35	28	25.9
	36 – 60	63	58.3
	>60 years	17	13.9
Gender	Male	91	84.3
	Female	17	15.7
Marital Status	Single	4	3.7
	Married	104	96.3
Education Level	Diploma and degree	8	4.6
	No formal education	55	50.9
	Primary school	43	39.8
	Secondary school	2	1.9
Family size	1 – 5	61	56.5
	6 – 10	43	39.8
	>11	4	3.7
Total		108	100.0

Table 3: Characteristics of Microenterprises working on fishpond farm

Name of Microenterprises	Location	No of ponds owned	Members of Microenterprises		Total
			Male	Female	
Gudeta bula cooperative	Omo Nada	4	15	15	15
Abdi gudina cooperative	Omo Nada	4	4	14	18
Chafe gode cooperative	Omo Nada	2	4	1	5
Hulle 1st Cooperatives	Omo Nada	3	10	-	10
Hulle 2nd cooperatives	Omo Nada	1	5	1	6
Chafe Bali cooperative	Omo Nada	4	21	3	24
Ifa Boru Cooperatives	Omo Nada	3	4	1	5
Nasiba Cooperatives	Omo Nada	2	8	2	10
Ibso Cooperatives	Omo Nada	1	4	1	5
Lafto Batte cooperatives	Omo Nada	1	1	2	3
Nadhi Gibe Agriculture office	Nadhi Gibe	1			
Busa Kebele FTC pond	Nadhi Gibe	1			
Doyo Yaya kebele FTC	Omo Nada	1			
Chayina kamp	Omo Nada	1	3	7	10
Total		29	79	47	111

4.2. The Boom of Pond Aquaculture

4.2.1. Procedures Followed to Start Fishpond Farming

Pond aquaculture extension serves as an educational process aimed at transferring scientific and technological aquaculture knowledge to farmers, enhancing their existing farm operation and management skills. Adequate agricultural advice from the extension officer plays a crucial role in fish pond farming. Key procedures such as site selection, pond excavation, and fingerling collection are essential steps in initiating fishpond farming activities. The findings reveal that 71.3% of respondents commenced fishpond farming after receiving guidance from the Woreda Agricultural Office Extension and Jimma University. The guidance covered aspects such as site selection criteria (favoring clay soil with water retention capacity), pond excavation, pond fertilization with manure, fish feeding practices, and fingerling stocking methods. Conversely, 28.7% of respondents began their fishpond farming journey by observing their neighboring fishpond farmers without formal training. All respondents identified improving their nutritional status and generating income for their families as the primary motivations for embarking on fish pond farming, as summarized in Table 4.

Table 4: Procedures to follow in order to start fishpond farming

Training	Frequency	%
Training train from agricultural extension and by any institution	**77**	**71.3**
Not trained	**31**	**28.7**
Kind of advice given by agricultural extension worker and Jimma University		
Selection of place to make ponds, Dig ponds, Fertilize ponds, Feed fish in ponds and How to put fingerlings	**77**	**71.3**

When examining the experience of fish ponds farming in the study area, the survey result indicate that fishpond farming was initiated in 2004 in Shabe Sombo district. The data further reveals that the highest numbers of fishpond (51) were constructed in 2008 in Omo Nada. From 2004 to 2015, about 120, 14, 10 1nd 2 pond aquacultures were constructed in Omo Nada, Shabe Sombo, Nadhi Gibe and Sokoru, respectively, as illustrated Table 5.

Table 5: Pond aquaculture booming from 2004 to 2015 in the study area

Location (Woreda)	Year of construction										Total
	2004	2007	2008	2009	2010	2011	2012	2013	2014	2015	
N. Gibe	0	0	0	1	4	0	2	3	0	0	10
O. Nada	0	2	51	23	7	2	26	4	4	1	120
S. Sombo	1	0	0	3	3	0	5	2	0	0	14
Sokorru	0	1	0	1	0	0	0	0	0	0	2
Total	1	3	51	28	14	2	33	9	4	1	146

N. Gibe=Nadhi Gibe, O. Nada=Omo Nada, S. Sombo=Shabe Sombo

4.2.2. Status of Fish Pond Development in the Study Area

In the study area, a total of 146 fish ponds were constructed, with 68.5% classified as functional and 31.5% as non-functional. According to survey assessments and personal observations, the distribution of these ponds was as follows: 120 (82.2%) in Omo Nada, 14 (9.6%) in Shabe Sombo, 10 (6.8%) in Nadhi Gibe and 2 (1.4%) in Sokoru. Among these ponds, 69.2%, 7.5%, and 4.1% of ponds in Omo Nada, Shabe Sombo, and Nadhi Gibe, respectively, were considered productive (Figure 2a), while 30.82%, 2.72%, 2.12%, and 1.4% of fish ponds found in Omo Nada, Nadhi Gibe, Shabe Sombo, and Sokoru, respectively, were non-functional (Figure 2b). A summary of productive and nonproductive fish pond distribution in the study area is shown in Table 6. For a comprehensive interview of fishpond status, including their coordinated locations please refers to Anex-II.

Figure 2: Functional (a) and nonfunctional (b) ponds in different Kebeles of the study area

Table 6: Summary of functional and nonfunctional fishponds in the study area

Study area (Districts)	Total No. Pond (%)	Functional (%)	Nonfunctional (%)
Omo Nada	120 (82.2)	83 (69.2)	37 (30.8)
Nadhi Gibe	10 (6.8)	6 (4.1)	4 (2.7)
Sokoru	2 (1.4)	0	2 (1.4)
Shabe Sombo	14 (9.6)	11 (7.5)	3 (2.1)
Total	146 (100)	100 (68.5)	46 (31.5)

The results from surveys, interviews, and personal observations indicate that the majority of fish ponds in the study area were constructed by smallholder farmers (80.1%), with a smaller proportion being established by microenterprises (19.9%). Furthermore, the study reveals that fish pond farming is most common in Omo Nada district (82.2%), followed by Shabe Sombo (9.6%), Nadhi Gibe (6.8%), and Sokoru (1.4%), as summarized in Table 7.

Table 7: Fish farming category in the study area

Area	Farm Category		Total
	Microenterprise	Small Holder	
Nadhi Gibe	2 (1.4)	8 (5.5)	10 (6.8)
Omo Nada	27 (18.5)	93 (63.7)	120 (82.2)
Shabe Sombo	0	14 (9.6)	14 (9.6)
Sokorru	0	2 (1.4)	2 (1.4)
Total	29 (19.9)	117 (80.1)	146 (100)

A total of 108 fish pond farmers participated in this study, comprising 94 smallholder farmers and the 14 leaders of microenterprises. Among smallholder farmers, the majority (82.4%) reported owning less than two ponds, while 3.7% and 0.9% of respondents reported owning 3 to 4 ponds and more than four ponds. respectively. For microenterprises, 8.3%, 2.8%, and 1.9% reported owning less than two, more than four, and two to three ponds, respectively, as shown in Table 8.

Table 8: The burden of ponds owned per small holder farmers and Microenterprise (n=108)

Farm Category	Number of Pond Owned			Total
	<2	3-4	<4	
Microenterprise	9 (8.3)	2 (1.9)	3 (2.8)	14 (13.1)
Small Holder	89 (82.4)	4 (3.7)	1 (0.9)	94 (87.0)
Total	98 (90.7)	6 (5.6)	4 (3.7)	108 (100)

The depth, length, height, and width of earthen fish ponds depend on factors such as the type of fish being cultivated, desired production levels, local conditions, and available resources. The design of the pond should take into account factors like water exchange, pond depth, size, shape, and proper placement of inlets and outlets for water circulation. The most common pond dimensions were 4 m to 20 m in length and 5 m to 20 m in width. The most common depth was 0.68m to 2m. The average area (m^2) and stocking density (F/m^2) across ponds were 123.295±65.0914 and 2.16±1.197, respectively (Table 9).

Table 9: The average dimensions, area, depth and stoking density of fishpond in the study area

Pond Characteristics	**Minimum**	**Maximum**	**Mean ± SD**
Length (m)	4.0	20.0	8.781±1.7558
Width (m)	5.0	20.0	13.308±4.9766
Area (m^2)	20.0	400.0	123.295±65.0914
Depth (m)	0.68	2.00	1.1234±0.27194
Stocking density(fish/m^2)	1	11	2.16 ± 1.197

The majority of ponds (98.6%) were earthen ponds (Figure 3a), and 1.4% were concrete ponds (Figure 3b). The preference for earthen ponds over concrete ones was primarily due to their simplicity and cost-effectiveness in construction, as noted by the users who continued to utilize concrete ponds.

a

b

Figure 3: Earthen fishponds (a) and Concrete fish pond (b) in the study area.

The results from Table 10 below present the major characteristics of fishponds, including fish farm categories, species of fish stocked in ponds, sources of water supply, types of ponds, and sources of fingerlings. The main species cultured in the ponds were Nile tilapia (96.6%), with a small proportion (1.4%) stocked mixed tilapia-catfish and Labeobarbus. About 2.1% of ponds were not stocked with fish. In terms of water supply, 70.5% of participants obtained their water from streams or rivers, while 26.7%, 2.1%, and 0.7% sourced their water from springs, ground, and boreholes, respectively. This reliance on surface water sources suggests potential challenges in water quality and availability, impacting aquaculture operations.

Regarding fingerling sources, 52.7% of ponds obtained fish fingerlings from Batu and Sabeta research centers, while 36.3, 6.2, and 2.7% sourced fingerlings from Gilgel Gibe reservoir and rivers, respectively. All but 2.1% of ponds were not stocked with fingerlings. Most farmers utilized fish nets and mosquito nets for fish harvesting.

Table 10: Fishpond Characteristics in the study area

Characteristics of fish pond	No. of ponds	Percentage
Types of Pond		
Concrete pond	2	1.4
Earthen pond	144	98.6
Source of fingerlings		
Gilgel gibe Reservoir	9	6.2
Research centers	77	52.7
Rivers	4	2.7
Transfer from pond	53	36.3
Species of fish stocked in pond		
Catfish(Clarias gariepinus) and Labeobarbus	2	1.4
Tilapia (Oreochromisniloticus)	141	96.6
Pond constructed fish not stocked	3	2
Source of water supply	3	2.1
Borehole	1	0.7
Ground/Hand pump	3	2.1
River/stream	103	70.5
Spring	39	26.7
Total	146	100

4.2. Status of Length and Weight of Fish in fishpond

A total of 64 specimens of Nile Tilapia harvested from 57 fishponds measured and the mean in total length (TL) from 10.01±1.3 cm to 31.87±0.4 cm and the mean weight range from 13.08±1.3 g to 189.15±8.7g were recorded (Table 11). The total length (cm) of each fish was taken using a measuring board and body weight was measured using a digital balance (Figure 4).

Table 11**:** Length and weight of Nile Tilapia from fishpond during study period

Length group (cm)	No of fishes	Mean length (cm)			Mean weight (g)		
	N	Minimum	Maximum	Mean±SD	Minimum	Maximum	Mean±SD
8-15cm	4	8.0	13.8	10.01±1.3	10.5	16.0	13.08±1.3
15-18cm	9	14.5	17.8	16.2±0.3	25.5	40.0	29.76±1.5
18-21cm	14	18.1	20.5	19.5±0.2	42.0	56.1	47.16±1.1
21-24cm	15	21.0	23.5	22.05±.2	56.7	95.0	74.99±3.54
24-27cm	12	24.0	26.8	25.14±0.3	101.8	127.3	111.47±2.5
27-31cm	6	27.5	30.5	28.38±0.4	135.5	171.5	147.15±5.59
30-33cm	4	31.0	32.8	31.87±0.4	170.5	210.0	189.15±8.7

Figure 4: Measurement of the body length and weight of fish

4.3. Physicochemical Characteristics of Aquaculture Ponds

Physicochemical parameters play a crucial role in effective fishpond management, as they encompass various physical and chemical factors that influence the water quality and overall health of fish within the pond. The results of the major physicochemical parameters measured to assess fishpond water quality are summarized as follows:

Water temperature: The results from Table 12 indicated an average pond water temperature of 25.02±1.89, 21.81±1.67, and 21.72±1.85 °C for fish reared in the four districts: Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively.

Dissolved Oxygen (mg/l): The average dissolved oxygen (DO) content of water among the different treatments is presented in Table 12. The average values of DO were 6.18±1.47, 5.0760±1.59, and 4.34±2.14 mg/l for the earthen ponds irrigated in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively.

Total dissolved solids (TDS mg/l): The average total dissolved solids **(**TDS**)** content of water among the different treatments is presented in Table 12. The average values of TDS were 65.74±30.67, 46.07±13.96, and 77.89±29.98 mg/l for the earthen ponds irrigated in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively.

Electric Conductivity (EC): During this study, conductivity levels of 94.28±44.16, 74.80±22.65, and 120.17±51.31 µS/cm were recorded in the Omo Nada, Nadhi Gibe, and Shabe Sombo ponds, respectively.

Hydrogen Ion Concentration (pH): The average values of pH for the different treatments in the present study are illustrated in Table 11. As shown in this table, the overall pH values were 7.40±0.71, 6.40±0.21, and 7.10±0.56 in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively.

Turbidity (water transparency and color): The Secchis disk recording were conducted alongside visual color observation to gather valuable information about water productivity (Figure 5). Results depicted in Table 12 illustrate the average means of Secchi disk readings, which were 10.66±3.26, 13.18±2.21, and 11.04±2.42 inches in the water of earthen ponds in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively.

Table 12: Physicochemical characteristics of Fish Ponds in the study area ANOVA test

Area	Temp.	DO	TDS	pH	Salinity	EC	Turbidity
Omo Nada	25.02±1.8	6.18±1.47	65.74±30.6	7.40±0.7	2.93±1.21	94.28±44.1	10.66±3.2
Nadhi Gibe	21.81±1.6	5.08±1.59	46.07±13.9	6.40±0.2	2.60±0.5	74.80±22.6	13.18±2.2
Shabe Sombo	21.72±1.8	4.34±2.1	77.89±29.9	7.10±0.6	3.83±1.4	120.17±51.3	11.04±2.4
Sokoru	-	-	-	-	-	-	-
Overall	24.44±2.22	5.98±1.41	65.94±30.2	7.31±0.7	3.00±1.24	96.16±44.59	10.85±3.13
M^2	0.606	7.59	2839.53	0.088	4.59	9667.23	16.54
F	0.122	3.91	3.189	0.174	3.032	5.058	1.700
P value	0.728	0.051	0.077	0.678	0.085	0.027	0.195

M^2 =Mean square

Figure 5: The visual color of the pond water is important reflection of the basic production processes

4.4. Socio-Economic Contribution Of Pond Aquaculture

Most pond fish farmers in the study area did not keep any written records of the costs and returns of fish culture. However, it is assumed that they possess a sharp memory and can estimate everything in concentration with their farm business. The result from Table 13 indicates the total cost of impute and output for fish ponds in the study area were 1,463,449.82 and 4702.29 ETB, while the total profit was less than the total impute (-1,458,747.53). During the focus group discussion (FGD), the farmers reported that the average revenues gained from selling fingerlings were 1665.69 ETB, and the average fish consumed were 43.38 kilograms (valued at 3036.6 ETB).Interestingly, the majority of farmers stated that they did not benefit from selling fish meat from the pond but rather found more success in selling fingerlings and consuming the fish at home. The result of the study indicates there are only 131 (28 from fingerlings and 103 from home consumption) households that benefited from fishpond production. When we consider the total imputed cost, the study indicates that there were 146 fish ponds constructed with a total average cost of 945,500.15 ETB and stocked with a total cost of 90250.02. In conclusion the impute is greater than the output, and the majority of fishpond farmers did not benefit from the production (Table 13).

Table 13: **Cost, Returns and Profit of Pond Fish Production**

Variables	No. owners	No. average	Ave. cost	Total cost
Output (income)				
Average no. Fingerling sold	28 (soled (fingerling)	699.87 (fingerling)	2.38	1665.69
Average no. Fish consumed in kg	103 (consumed fish)	43.38 (meat)	70	3036.6
Average no. Fish meat soled in ton	-	-	-	-
Total output (Total Revenue)				**4702.29**
Impute Cost				
Pond construction cost		146 (pond)	8836.45	945,500.15
Fingerling cost for stocking		105 (pond)	859.524	90250.02
Feed cost		105(pond)	4073.33	427699.65
Total impute (Cost)				**1,463,449.82**
Profit = TR-TC=4702.29-1,463,449.82				**-1,458,747.53**

4.5. Determinant Factors for Successful Pond Aquaculture

The result of the study also indicates that the major influencing factors such as categories of pond, source of fingerlings, water management, pond fertilization, types of soil, availability and status of fence, clearing surrounding pond (grass, trees), physical structure of ponds, water fertilization in terms of color, shape of pond, topography, and knowledge skill of farmer were significantly (P =<0.05, at 95% CI) affecting functionality and productivity of fish ponds in the study area. However, the result indicates that the functionality and productivity of the fish pond in the study area were not affected by the source of water. In general, the majority of risk factors affecting the development of fish ponds were highly related to the management practices of the pond aquaculture (P = 0.001) (Table 14).

Table 14: Factors affect development of fish Pond production.

Variables (Risk factors		No of pond	Functional	Non functional	χ^2	P-Value
Categories of pond	Cooperatives	29	26	3	7.913	0.005*
	Small holder	117	74	43		
Source of fingerlings	Gilgel Gibe Reservoir	9	5	4	17.593	0.001
	Research centers	77	62	15		
	Rivers	4	4	0		
	Transfer from pond	53	29	24		
	No fish seed stoked	3	0	3		
Water management	Yes	97	92	5	106.249	<0.001**
	No	49	8	41		
Pond fertilization	Yes	94	89	5	107.133	<0.001**
	No	52	11	41		
Types of soil	Clay soil	100	84	16	36.821	<0.001**
	Loam soil	5	0	5		
	Sandy soil	38	15	23		
	silt soil	3	1	2		
Source of water	Borehole/Ground	4	2	2	3.565	0.312
	River/stream	104	75	29		
	Spring	38	23	15		
Availability and status of Fence	Strong fence	24	24	0	117.069	<0.001**
	Medium	10	9	1		
	Weak fence	35	34	1		
	No fence	77	33	44		
Clearing surrounding pond (grass, trees)	Good (Cleared)	26	26	0	129.570	<0.001**
	Very good (Regularly clearing)	8	7	1		
	Fair (sometimes)	46	46	0		
	Not cleared	66	20	46		
Physical structure of ponds	Very good	6	6	0	128.558	<0.001**
	Good	15	16	0		
	Medium	49	48	1		
	Poor	32	30	45		

Water fertilized in terms of color	Turbid colors	37	36	1	128.270	<0.001**
	Deep green	1	0	1		
	Light greenish color	49	48	1		
	No greenish color (fresh water)	17	16	1		
	No water in the pond	42	0	42		
Topography	Gently sloping	88	73	15	61.508	<0.001**
	Hilly area	25	2	23		
	v-shaped valley	23	19	4		
	wide flat valley	10	6	4		
Knowledge Skill of farmer	Very good	5	5	0		
	Good	36	34	2		
	Medium	4	4	0		
	Fair	61	56	5		
	Poor knowledge	41	40	1		

*significant **=Highly Significant

4.5.1. Constraints Hamper Pond Aquaculture Farm in the Study Area

During the study, fishpond farmers were asked whether they had benefited from fishpond farming. In responding, the majority of respondents had not harvested any fish until now, and some of them had sold fingerlings. They were also asked about the major problems they faced during fish pond farming, and they complained that there were several problems such as high construction costs, a lack of good sources of fingerlings, a lack of organized markets, a lack of materials such as fishing gear for harvesting, a lack of advice (training), inadequate water supply, inadequate transport facilities, predators, a shortage of feeds during farm cultivation, and a lack of modern equipment for caching fish and making ponds (Table 15). Many fishpond farmers may lack adequate knowledge and skills in fish farming techniques, such as pond construction, fish stoking and feeding, water quality management, and disease control. By addressing these challenges, fishpond farming in the study area can be improved, leading to increased productivity and profitability for farmers. In conclusion, we concluded that these problems have contributed to the low adoption of fishpond farming and consequently the low production of fish in the study area.

Table 15: Constraints that hamper fishpond farming in the study area

Types of constraints	Respondents response	Availability of fish in fishpond and harvesting		Total response N (%)	χ^2	P Value
		Yes	No			
Predators	No	41	31	72 (49.30)	8.78	0.003
	Yes	59	15	74 (50.7)		
Inadequate	No	20	3	23 (15.8)	11.69	0.009
Transport	Yes	80	44	124 (84.9)		
Inadequate	No	77	20	97 (66.4)	20.89	0
water supply	Yes	23	26	49 (33.6)		
Lack of training	No	9	2	11 (7.5)	11.582	0.003
	Yes	91	44	135 (92.5)		
High	No	6	4	10 (6.8)	10.812	0. 029
construction cost	Yes	94	42	136 (93.2)		
Feeding	No	25	25	50 (34.2)	4.459	0.108
	Yes	75	21	96 (65.8)		
Accessibility of	Beach seine	2	0	2 (1.4)	63.8	0
modern	Beach seine and Gill net	5	0	5 (3.4)		
equipment for	Gill net	18	9	18 (12.3)		
harvesting	Gill net and Mosquito net	4	0	4 (2.7)		
	Mosquito net	54	0	54 (37)		
	No material access	17	37	54 (37)		
Total		100	46	146 (100)		

The result of the focus group discussion indicates that the most important predators of fish in ponds were otters, snakes, frogs, birds, etc. Snakes, frogs, and birds cause problems mostly in nursery and rearing ponds. They describe that only fishponds in the vicinity of the fish farmer's home are less likely to be affected by these predators than ponds that are isolated and seldom visited. Figure 6 indicates that birds are swimming in the fishpond to eat fish fry.

Figure 6: Image of a bird seeking fish in a fishpond in the study area

4.6. Opportunities to Develop Fishpond Farms in the Study Area

The study revealed that there are many opportunities to enhance the development of fishponds in the study area. The major opportunities include suitability of environmental conditions such as availability of year-round water supply, suitable soil for pond construction, availability of fingerlings in Gilgel Gibe Dam, natural resource availability, technology and knowledge transfer, and the interest of farmers. The abundance of natural water resources, such as rivers, streams, groundwater, and wetlands, is increasing recognition of the potential economic benefits of aquaculture. In addition, with a growing population and increasing incomes, the rising demand for fish protein and fish pond aquaculture can help meet this demand and contribute to food security, which is part of the country's strategy.

The presence of a year-round source of water in the study area is one of the crucial factors that determine the success of the fish pond farm in the area. On the other hand, the availability of local feeds enhances the integration of fishpond farms with other agricultural activities such as vegetables, honey production, and chickens. In addition, there was a positive attitude towards fish consumption in the study area. According to Wakjira et al. (2019) and Khan et al. (2018), the success of an aquaculture plan depends on local availability, water supply, local feeds, and the possibility of integrating fish farms with other agriculture activities, as well as the fish consumption and farming attitude of the local community, which are vital for aquaculture development. On the other hand, the geographic characteristics of all districts, which are full of the natural resources needed for aquaculture development, favor suitable conditions to establish small-scale fish farm development. Overall, the selection of topography for fish pond aquaculture should be based on the availability of water (Figure 7), soil suitability, proper drainage, protection from flooding, accessibility, and environmental sustainability.

Figure 7: Major resources that create opportunities for development of fishpond in the study area

5. DISCUSSION

5.1. Characteristics of Study Participants

A total of 108 homeowners engaged in the fish production chain, with males accounting for 84.25% and females for 15.75%. This means that, on average, men are slightly more likely than women to engage in fish farming activities in the research area. The study aligns with Omitoyin and Tosan's (2012) report, indicating that male fishers tend to have a greater dominance in fish harvesting activities. Age was an important demographic characteristic examined in this study. The mean age of the respondents was almost 42.09±10.060 years, suggesting that the youth population is actively involved in the fish farming business. The highest age frequency was observed in the range of 36–50 years, accounting for 58.3% of the respondents, irrespective of gender. The number of individuals economically supported by the family heads varied from 1 to 17. The majority of family heads (56.5%) supported a family size ranging from 1 to 5 individuals. This finding suggests the responsibility of fishpond farmers to support their households. In terms of marital status, the results indicate that the majority of fishpond farmers interviewed were married, accounting for 96.3% of the respondents, whereas only 3.7% were single. Regarding the educational level of the participants, the study found that 50.9% of fishpond farmers had a non-formal education, while 39.8% had a primary education. A small proportion (7.4%) had secondary to a degree as their highest level of education. Oluwemimo and Damilola (2013) stated that years of schooling enables fishers understand the technical requirements of fish farming. This finding highlights the prevalence of lower educational attainment among fishpond farmers. Generally, education creates awareness among fishermen about fishery management strategies of the fishing sector. The findings contribute to understanding the demographics of the fish farming sector in the studied districts and can guide future interventions and policies targeted towards improving the inclusivity and overall development of fish pond farming, including promoting gender equality and addressing educational gaps.

5.2. The Boom of Pond Aquaculture

5.2.1. Procedures Followed to Start Fishpond Farming

Proper selection of a site is the most important factor for the success of a fish farm. Soil type, quality, and quantity of water available, as well as the requirements for filling and drainage of the pond, are important factors in starting a fishpond farm (FAO, 2014). And so, training the farmers on the procedures to follow to start fishpond farming is important. During the study period, the owners of fishponds were asked whether they were trained or not trained before starting a fishpond farm, and 71.3% of respondents started fishpond farming by taking awareness from Woreda Agricultural Office Extension and Jimma University on the selection of sites for making ponds (the site should have clay soil that has the capacity to hold water), how to dig ponds, how to fertilize ponds with manure, how to feed fishponds, and how to put fingerlings into the ponds, while 28.7% started by visiting their neighbor fishpond farmers without taking any train. Therefore, when evaluating and selecting sites for earthen fish pond siting, the source of water and its quality are some of the main factors to consider while ensuring that the water source has a high concentration of dissolved oxygen and optimal temperatures which should be kept at the right levels throughout the culture period among other critical factors (Makori et al., 2017).

5.2.2. Status of Pond Aquaculture Development in the Study Area

The results of the study indicate that there were a total of 146 fish ponds in the study area, with 68.5% classified as functional and 31.5% as non-functional ponds. Among the districts, Omo Nada had the highest percentage of fishpond farming (82.2%), followed by Shabe Sombo (9.6%), Nadhi Gibe (6.8%), and Sokoru (1.4%). It is worth noting that a significant proportion of the constructed ponds, particularly in Omo Nada, were nonproductive, accounting for 30.8%, while 2.7, 2.1, and 1.4% of the fishponds had lower percentages of nonproductive fish, respectively. The majority of smallholder farmers (82.4%) had less than two ponds, indicating a limited scale of fishpond farming among them. This finding suggests that most smallholder farmers face challenges such as a lack of training, water scarcity, and limited access to good fingerling sources, which may restrain their ability to expand their fish pond operations. The most common pond dimensions observed in the study were 4 m to 20 m in length, 5 m to 20 m in width, and 0.68 m to 2 m in depth.

Recommended stocking density in tilapia ponds is 3–8 fingerlings per m^2 (FAO, 2010; Pant et al., 2019). If the recommended stocking density (number of fingerlings stocked per m2) of 3–8 fingerlings per m2 is followed, the survival rate is assumed to be 90%; if the average tilapia size at harvest is assumed to be 300 g, then productivity is expected to be between 0.81 and 2.16 kg per m2 (Ragasa et al., 2022). In the study area, data show a stocking density of 2.16±1.197 fish per square meter. 22% of farmers followed this recommendation, but 75% were understocked and 3% were overstocked. The average pond area was 123.295±65.0914 square meters. In the study area, the majority (98.6%) of the fish ponds were earthen ponds, while only 1.4% were concrete ponds. According to the Technical Guide for Tilapia Farming, published by the Centre for the Development of Industry, “Earthen ponds are more commonly used in tropical fish farming. A good pond will show the following characteristics: a well-designed water supply but also easy drainage; good impermeability of the pond as a whole; strength and integrity of the pond's walls and edges; access to and the possibility to work around the pond. Nile tilapia was the main species cultured, accounting for 96.6% of the ponds, followed by mixed tilapia-catfish and Labeobarbes (1.4%). Small percentages (2.1%) of the ponds were not stocked with fish. Regarding the source of water supply for fish ponds, 70.5% of the participants obtained their water from streams or rivers, indicating a reliance on natural water sources. A smaller proportion of participants (26.7%) used spring water, while ground and borehole water constituted 2.1% and 0.7%, respectively. It is worth noting that the majority of participants relied on well water for their fish pond operations, which may indicate low operational efficiency due to the limited availability or quality of water resources in the area (Mishra, 2023).

5.3. Status of Length and Weight Fish in the Fishpond

During the study period, both the length and the weight of 64 fish (Nile Tilapia) harvested from the farmer’s fishpond were randomly selected and measured. The result of this measurement shows that the weight of the fish proportionally increases as the body length of the fish increases. As the mean size of length increased from 10.01±1.3 cm to 31.87±0.4 cm, the mean weight also proportionally increased from 13.08±1.3 g to 189.15±8.7 g (see result section on Table 9). From this result, we can understand that the population and health status of the fish in the fishpond were good during the study period. As a consequence, it can be said that length and growth are interrelated. According to Keri et al. (2011), the correct growth of all living organisms, including plants and animals, increases with an increase in body length. According to Mansor et al. (2010), a positive length-weight relationship indicates the good growth condition of fish associated with maturity and breeding. In the study area, the length and weight of the fish are positively related. The majority of fishponds have nearly similar fish that are nearly equal in length and weight. During the focus group discussion, the farmers reported that there is no fast growth or stunted growth in some fishponds, and training management and feeding methods for fish are important.

5.3. Physicochemical Characteristics of Pond Aquacultures

The measurement of the physicochemical parameters of water gives a first estimate of its quality because they have an influence on several physical, chemical, and biological processes (Coulibaly, 2013). They therefore help to assess the quality of the water and to know whether or not it is suitable for aquatic life (Dimon et al., 2014; Noumon et al., 2015) in general and that of fish in particular. The water used for the cultivation of fish will not give maximum production if the physico-chemical parameters are not optimal for fish and other aquatic organisms. Productivity depends on the physico-chemical characteristics of the water body (Huct, 1986).

Water temperature: Temperature and turbidity play an important role in pond productivity. It was established that the average values of pond water temperature in the study area were 25.02±1.89, 21.81±1.67, and 21.72±1.85°C for fish reared in the four districts: Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively. Slight but remarkable and significant differences were observed in water temperature among the ponds in the districts during the temperature measurements. It’s worth noting that the water temperature in Nadhi Gibe and Shabe Sombo fell below recommended temperature levels for optimal fish farming. The overall average water temperature of the study area was 24.44±2.22 °C, which is in the normal range and suitable for fish growth and production of Nile Tilapia. According to DeWalle et al. (2011) and other studies, the most preferred temperature range for optimal growth of tilapia is 25 to 27 °C, while the ideal pH ranges between 6 and 9.

Dissolved oxygen (mg/l): Fish need oxygen to survive, and the level of dissolved oxygen in the water determines their ability to respire. It was established that the average values of DO were 6.18±1.47, 5.0760±1.59, and 4.34±2.14 mg/l for the earthen ponds irrigated in Omo Nada, Nadhi

Gibe, and Shabe Sombo, respectively. During the entire study period, results indicated that the lower DO content (4.34±2.14 mg/l) was recorded for ponds in Shabe Sombo, while the highest DO content (6.18±1.47 mg/l) was recorded in Omo Nada. The ranges of DO for all ponds in the districts were within the acceptable limits. According to Ross (2002) and Bartholomew (2010), a DO concentration of 3 mg/L should be the minimum for optimum growth of tilapia and fish growth, and yields are greater in ponds with higher dissolved oxygen concentrations.

Dissolved oxygen is an environmental parameter that is not toxic to fish, even at very high concentrations. But an insufficient concentration of dissolved oxygen in the water can cause breathing difficulties for fish (Morin, 2012), which can lead to their death (Chouti et al., 2010). The most common and serious hazard in fishpond culture is the depletion of the dissolved oxygen level in the water. Low dissolved oxygen levels can lead to stress, suffocation, and even fish mortality. Gasping for air, especially during the early morning hours, is the most common behavioral symptom. The growth rate is seriously affected, and very often it may result in a mass fish kill.

Total dissolved solids (TDS mg/l): It was established that the average values of TDS were 65.74±30.67, 46.07±13.96, and 77.89±29.98 mg/l for the earthen ponds irrigated in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively. During the entire study period, results indicated that the lower TDS content (46.07±13.96 mg/l) was recorded for ponds in Nadhi Gibe, while the highest TDS content (77.89±29.98 mg/l) was recorded in Shabe Sombo ponds. High values of total dissolved solids (TDS) cause increased electrical conductivity (Goher et al., 2017) and may prevent light penetration and oxygenation of the aquatic environment (Attingli et al., 2016). They also affect the functions of the gills and kidneys and, subsequently, the survival and size of fish (Wright, 2009).

Electric Conductivity (EC): Electrical conductivity (EC) is a measure of how well a solution conducts electricity and is correlated with salt content. Conductivity is typically reported in units of µSiemens/cm (micro Siemens per centimeter). Freshwater fish generally thrive over a wide range of electrical conductivity. Some minimum salt content is desirable to help fish maintain their osmotic balance. Electrical conductivity (EC) can also be used to give a rough estimate of the total amount of dissolved solids (TDS) in water. Typically, the TDS value in mg/l is about half of the EC (Siemens/cm). Conductivity should change little during shipment to the laboratory (Nathan and Hugh, 2015). During this study, conductivity levels of 94.28±44.16, 74.80±22.65, and 120.17±51.31 μS/cm were recorded in the Omo Nada, Nadhi Gibe, and Shabe Sombo ponds, respectively. The optimal conductivity for high fish production differs from one species to another. The average EC values of fish ponds in the study area were within the normal range. Stone and Thomforde (2004) recommended a desirable range of 100–2000 μS/cm and an acceptable range of 30–5000 μS/cm for pond fish culture.

According to Bénech and Ouattara (1990), the maturation of fish, of course, is accelerated by the drop in conductivity. According to the WHO standards, the permissible range of EC for water is 150 to 500 µS/cm, which is an admissible and sufficient range for the survival and growth of fish and can also influence its productivity (Masood et al., 2022). Therefore, the present study indicated that the electrical conductivity of water samples was favorable for fish growth.

Hydrogen Ion Concentration (pH): The pH is an essential parameter for maintaining life in the aquatic environment, and its stability is very important in fish farming (Morin, 2012). Fish can be stressed in waters with a pH ranging from 4 to 6.5 and 9 to 11. Death is almost certain at a pH below 4 or above 11 (Kane et al. 2015). It was found that the overall pH values of pond water in this study were 7.40±0.71, 6.40±0.21, and 7.10±0.56 in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively. There were no insignificant differences among pH values in ponds between districts. Results indicated that pH values lied on the alkaline side at all water sources in Omo Nada and Shabe Sombo, while on the acid side in Nadhi Gibe, they varied generally between 6.1 and 8.11. The highest pH value (7.4) was recorded for ponds received Omo Nada, while the lowest pH value (6.4) was recorded for ponds in Nadhi Gibe. The pH recorded in this study is within the normal range. According to DeWalle *et al.* (2011) and other studies, the most preferred pH range for optimal growth of tilapia is between 6 and 9.

According to Stone and Thomforde (2003), the acceptable range for pond pH is 5.5–10. According to Nathan and Hugh (2015), most fish species do well within the pH range of 6.5 to 9.5. Chronic pH levels below 6.5 may reduce fish reproduction and are associated with fish die-offs that sometimes occur in the late winter. Newly hatched fish (fry) are often sensitive to pH levels above 9.0 to 9.5. A pH test is useful to detect possible mineral acidity. A pH reading below

4.5 indicates that there is strong mineral acidity, which is harmful to fish and difficult (and expensive) to neutralize. Low pH between 4.5 and 6.5 can often be corrected by the addition of crushed limestone (Nathan & Hugh, 2015).

Turbidity (water transparency and color): Turbidity refers to the clarity of water and is an indicator of suspended particles in fishpond farming. Water transparency, measured with a Sechi disc, aims to quantify the result of those processes that determine and modify visual color. However, low transparency may result from high turbidity alone, making it difficult to accurately assess the trophic or production level of the water. It was found that the average mean of Secchi disk readings was 10.66±3.26, 13.18±2.21, and 11.04±2.42 inches in the water of earthen ponds in Omo Nada, Nadhi Gibe, and Shabe Sombo, respectively. The range of water turbidity in this study was between normal ranges. Water transparency affects the penetration of light into the water and influences the productivity of the aquatic system (Goher et al., 2017). Low transparency may result either from high turbidity alone or from dense algal populations and thus cannot reflect the correct trophic or production level of the water (Mbuthia, 2020 & Bruckner, 2009).

5.4. Socio-Economic Contribution of Pond Aquaculture

The survey asked about the production, inputs, practices, costs, sales, and profits of the tilapia fish ponds of the farmers surveyed in the study area, with the results described below. Most pond fish farmers in the study area did not keep any written records of the costs and returns of fish culture. However, they rely on their memory and estimation skills to assess their farm business. The total cost of inputs and outputs for the fish pond in the study area was estimated to be 1,463,449.82 ETB, while the total profit was calculated to be -1,458,747.53 ETB. This indicated that the farmers experienced a loss in their fish farming operations. During the focus group discussion (FGD), the farmers reported that the average revenues gained from selling fingerlings were 1665.69 ETB, and the average fish consumed were 43.38 kilograms (valued at 3036.6 ETB). Interestingly, the majority of the farmers stated that they did not benefit from selling fish meat from the pond but rather found more success in selling fingerlings and consuming the fish at home.

5.5. Determinant Factors for Successful Pond Aquaculture

The result of χ^2 (Chi-Square) and P-Value**,** statistical values indicate the relationship between the availability of fish and the reported constraints as well as a low P-value (less than 0.05) suggests a statistically significant association between the constraint and fish harvesting in the study area. Various challenges that can hamper the success and productivity of fish pond farming faced the fish farmers as enlightened in the results. The major constraints affecting the overall success of fishpond farming were high construction costs (limitation of financial resources), a lack of materials for harvesting, and a lack of advice and training on the technology of fish farming. In addition, inadequate water supply, transport facilities, and access to markets, as well as the presence of predators, were other challenges directly affecting the survival and growth of fish in the ponds and altering the productivity of the fishponds. According to Shahim (2020), lack of scientific knowledge, extension services, and marketing problems are major problems that affect the success of fishpond farmers. However, the challenges facing fish farmers could easily be managed to ensure productivity. Mwangi (2008) explained that fish farmers can surmount challenges when important attention is given to their felt needs by the government or other donor agencies.

Hence, helping fishpond farmers access financial resources, establishing reliable sources of fingerlings, creating organized market systems, providing training and advisory services to farmers, ensuring adequate water supply and transportation facilities, implementing predator control measures, and promoting the use of modern equipment and technologies in fish farming are ways to enhance the productivity and profitability of fishpond farmers in the study area. Similarly, many recent studies indicate that aquaculture development in Ethiopia has been faced with a number of challenges, which include, mainly, a lack of cheap and efficient locally available fish feeds and a lack of locally selected and certified fish seeds. Likewise, a shortage of small-scale, low-cost aquaculture support for rural development, a lack of licensed fish seed multiplication centers, a scarcity of trained manpower, and a lack of government attention hinder aquaculture development in Ethiopia (Tilahun et al., 2016; Natea et al., 2017).

5.6. Opportunities to Develop Fishpond Farms in the Study Area

The study area has year-round water and suitable soil for pond construction, and there are different species of fish in Gilgel Gibe Dame, which is a major opportunity for fish pond farm development. The availability of local feeds can help the integration of fishpond farms with other agricultural activities such as vegetables, honey production, and chickens. In addition, there was a positive attitude towards fish consumption in the study area. According to Wakjira et al. (2019) and Khan *et al.* (2018), the success of an aquaculture plan depends on local availability, water supply, local feeds, and the possibility of integrating fish farms with other agriculture activities, as well as the fish consumption and farming attitude of the local community, which are vital for aquaculture development.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Among the total participants in the study, 91 were male and 17 were female. There were fourteen (14) microenterprises with 111 members (79 males and 47 females) who owned 29 ponds. About 71.3% of respondents started fishpond farming by taking awareness from Woreda Agricultural Office Extension and Jimma University on the selection of sites for making ponds, how to dig ponds, how to fertilize ponds with manure, how to feed fishponds, and how to put fingerlings into the ponds, while 28.7% started by visiting their neighbor fishpond farmers. There were a total of 146 fish ponds constructed in the study area, among which 68.5% and 31.5% were functional and non-functional ponds, respectively. Survey assessment and personal observation show that 120 (82.2%), 14 (9.6%), 10 (6.8%), and 2 (1.4%) were located in Omo Nada, Shabe Sombo, Nadhi Gibe, and Sokoru, respectively. The majority of ponds (98.6%) in the study area were earthen ponds, and 1.4% were concrete ponds. The most common pond dimensions were 4 m to 20 m in length and 5 m to 20 m in width. The most common depth was 0.68 m to 2 m. The average area (m2) and stocking density (per m2) across ponds were 123.295±65.0914 and 2.16±1.197, respectively.

Where fish culture is concerned, any characteristic of water that affects the survival, reproduction, growth, production, or management of fish in any way is a water quality variable. These are the variables that fish culturists should concentrate on and attempt to control to some extent and manage. The result of this study indicates that the water quality in aquaculture ponds met the quality for warm water culture. The average values of pond water temperature (24.44±2.22), dissolved oxygen (mg/l) (5.98±1.41), total dissolved solids (TDS mg/l) (65.94±30.16), electric conductivity (96.16±44.59), and hydrogen ion concentration (pH) (7.31±0.71) were in the normal range, and the warm water genus was more suitable for the water quality. The result of this study indicates that the majority of fishpond farmers in the study area have not benefited from fish farming. Participants of this study responded that there were problems related to access to good sources of fingerlings (83.6%), a lack of advice (training) (92.5%), inadequate water supply (33.6%), inadequate transport facilities (84.9%), predators (49.3%), a shortage of feeds during farm cultivation (65.8%), and a lack of modern equipment for caching fish and making ponds

(37%). However, it can be concluded that there are many opportunities that can enhance the development of fishponds in the study area. The major potential opportunities include the suitability of environmental conditions such as the availability of year-round water supply, suitable soil for pond construction, the availability of fingerlings in Gilgel Gibe Dam, and the interest of farmers. In general conclusion, physicochemical characteristics of the fishpond are favorable for fish production and there are opportunities for further pond aquaculture booming and increasing pond aquaculture benefits of local community, economically and socially through job creation, income generation, and improved food security. Therefore managing the constraints and optimizing the construction and productivity of aquaculture ponds for small-holder aquaculture farmers is important. Based on this conclusion, the following recommendations are forwarded:

6.2. Recommendations

Based on these findings, here are some recommendations for fish farmers:

- Investigate cost-reduction strategies for pond construction, fingerling obtaining, or alternative feed sources.
- Promote best practices through farmer education programs, facilitate access to high-quality fingerlings from reputable sources, and explore the use of spring water for ponds.
- Encouraging better record-keeping practices among farmers would allow for more accurate data collection and informed decision-making.
- Facilitate access to fish feeds and essential materials through partnerships or distribution networks.
- Develop and implement training programs to equip farmers with necessary aquaculture knowledge.
- Conduct further research to gain a more comprehensive understanding of challenges and opportunities in the area.

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8. Annexes

Annex I: Questionnaire about Aquaculture Development.

The purpose of this questionnaire is to expand people's understanding and awareness about aquaculture pond development. This quiz should take no more than twenty minutes to complete. Please keep in mind that your response is fully secret, and your identity will not be published in any reports of the results. Your specific response will not be shared with anyone. Please respond to the question.

I. Individual Questionnaires for Aquaculture Fish Farmers.

1. ID Number, ____Full Name__________________________Gender ____ Age______ Fish farming experience________________
2. Are you interested fish farming? A. Yes, B. No
3. Have you ever received training on fish culture? A. Yes B. No, If yes, how many times?_______, if No, why?____________________
4. How many ponds do you have? __________, what is the size of each pond? _________
5. Culture system A. Extensive B. Intensive C. semi intensive
6. Location of the ponds in terms:
   6.1 District name______________________________
   6.2 Specific name of the locality___________________
   6.3 GPS location: Latitude_____________, and longitude____________, Altitude_________
   6.4 Topography: soil suitability, gravitation flow of water _________________, accessibility____________and availability of sustainable soil texture________________

7 Year of construction _________, a body who constructed the ponds___________________

8. Categories of pond A. Self B. Cooperative, C. __________

9. Which of the following structures do you use in fish culture? A. Earthen ponds B. Concrete ponds C. Plastic tanks D. Other__________

10. Dimensions of pond in length (L) _________, width (W) _______, height (H) ________, depth (S) ______. Area (A) ______, volume (V) _______ width, length and depth determine the volume of water needed to fill the pond.

11. Cultured fish species stocked? A. Nile tilapia __, B.African catfish__C. Coman carp __ year fish was first stocked_____________, stocking rate of fish for each pond___________________

12. Aquaculture inputs

12.1. Where do you get your fingerlings for stocking? a. River b. Irrigational canals C.Gilgel gibe reservoir d. Other ________________

12.2. Cost of fingerlings________________

13. Do you feed your fish? A. Yes__ B. No__. If yes, a. local__ feed b. imported feed__ C. Both__ If imported feed, how much is 1kg of feed cost______?

14. Pond water management

14.1 Do you practice any water management in your fish farm pond? a. Yes b. No if yes, what type of water management?

a. Occasional water exchange

b. Testing the water temperature and dissolve oxygen

c. Testing the pH of the Water

d. Conducting all of the above

e. Conducting none of the above

14.2 Has pond been fertilized? A. yes B. no, if yes, type of fertilizer A. Organic B. Inorganic

15. Stocking density ________________________

16. Type of soil ____ A.clay soil B. sandy soil C. loam soil D. silt soil

17. Which source of water do you use for fish farming? A. Well, B. Borehole C River/ Stream D.rainfall

18. Current conditions of the ponds (Management status**)**

18.1 Pond management status: A. poor B. good (i.e. physical structure of the ponds, pond surrounding cleared for grass and other vegetation, fenced)

18.2. How did you manage your fish pond? A. Occasional water exchange, C. testing the water temperature and DO. C. Testing pH of the water D .conducting all of the above

18.3. Do you use aerators in your fish pond? A. Yes B. No

18.4. If your answer on 18.3 is yes, what type of aerators do you use? A mechanical B electrical C. oxygen pump D. Others________________________________

19.Socio-economic impacts of the ponds

19.1. Establishing cost of the ponds______________________________________

19.2. Running costs: Feed cost________________, Fingerling cost_________________, etc.

19.3. Harvest cycle______________ and number of cycles harvested_____________________

19.4. Average amount of fish harvest (number of kg) per cycle_________________________

19.5 Amount of income generated per/year________________________

19.6. Amount of fish consumed/utilized at household level___________________________

19.7. Do you encounter any mortality in your fish pond? A. yes B. no

19.8 If your answer on 19.7 yes, at what stage of production? A. During stocking B. immediately after stocking during harvesting D. During hot climate E. Other_______

20. Would you consider the following challenges in your fish farming?

A. Economy-high construction and production cost

B. dropping price of the product

C. Competition- Domestic import

D. Pollution-Environmental issues

E. License and regulations from the authorities

F. Other______________________

21. Opportunities of developing pond aquaculture in the area

A. Suitability of environmental conditions (Ambient and water temperature, soil type, topography/elevation, availability of ample water)
B. Availability of fingerlings
C. Availability of fish feed ingredients
D. Interest of farmers
E. Extension support from the local (district or zone) agriculture office
F. Knowledge and skill of fish farmers
G. Others____

Thank You!

Annex II: Fishponds in the study area with their coordinated loctions.

Woreda	Coordination	Kebele	Pond Status
Omo Nada	7º33.8273'N,37º04.0238' E	Jato Abe	Functional
Omo Nada	7º33.8273'N,37º04.0238' E	Jato Abe	Functional
Omo Nada	7º45.2092'N,37º11.5239'E	Waktola	Functional
Omo Nada	7º45.2092'N,37º11.5239'E	Waktola	Functional
Omo Nada	7º45.20925'N,37º11.5239'E	Waktola	Functional
Omo Nada	7º45.20925'N,37º11.5239'E	Waktola	Functional
Omo Nada	7º45.20925'N,37º11.5239'E	Waktola	Functional
Omo Nada	7º36.8013'N,37º08.1587'E	Toli beyem	Functional
Omo Nada	7º41.3958'N,37º13.5776'E	Sayo adami	Non Functional
Omo Nada	7º38’3.9282'N,37º16.7383'E	Doyo Yaya	Non Functional
Omo Nada	7º38’3.9292'N,37º16.6373'E	Doyo Yaya	Functional
Omo Nada	7º41.3176'N,37º13.4496'E	Sayo adami	Non Functional
Omo Nada	7º41.3176'N,37º13.4496'E	Sayo adami	Non Functional
Omo Nada	7º36.5841'N,37º13.7599'E	Nada Sokote	Functional
Omo Nada	7º36.5841'N,37º13.7599'E	Nada Sokote	Functional
Omo Nada	7º36.5841'N,37º13.7599'E	Nada Sokote	Functional
Omo Nada	7º36.0612'N,37º13.7005'E	Nada Sokote	Functional
Omo Nada	7º37.4675'N,37º14.5100'E	Nada Sokote	Functional
Omo Nada	7º37.4210'N,37º14.6529'E	Nada Sokote	Functional
Omo Nada	7º36.0863'N,37º13.6747'E	Nada Sokote	Functional
Omo Nada	7º36.2307'N,37º13.6601'E	Nada Sokote	Functional
Omo Nada	7º36’29.6385'N,37º13’43.1184'E	Nada Sokote	Functional
Omo Nada	7º36’29.6385'N,37º13’43.1184'E	Nada Sokote	Functional
Omo Nada	7º36’10.73857'N,37º13’43.1268'E	Nada Sokote	Functional
Omo Nada	7º36’27.5386'N,37º13’43.1198'E	Nada Sokote	Non Functional
Omo Nada	7º36’27.5386'N,37º13’43.1198'E	Nada Sokote	Non Functional
Omo Nada	7º36’27.53650'N,37º13’45.3198'E	Nada Sokote	Functional
Omo Nada	7º36’27.53650'N,37º13’45.3198'E	Nada Sokote	Non Functional
Omo Nada	7º36’27.53650'N,37º13’45.3198'E	Nada Sokote	Non Functional
Omo Nada	7º36’10.3764'N,37º13’37.72319'E	Nada Sokote	Functional
Omo Nada	7º36'10.2854’,37º13’43.5647’E	Nada Sokote	Non Functional
Omo Nada	7º36’10.5631'N,37º13’39.2980'E	Nada Sokote	Functional
Omo Nada	7º36'10.2854’,37º13’43.5647’E	Nada Sokote	Non Functional
Omo Nada	7º36’12.7699'N,37º13’35.8626'E	Nada Sokote	Functional
Omo Nada	7º36’10.5601'N,37º13’39.2609'E	Nada Sokote	Functional

Omo Nada	7º36’10.5631'N,37º13’39.2980'E	Nada Sokote	Non Functional
Omo Nada	7º36’12.66317'N,37º13’39.3420'E	Nada Sokote	Non Functional
Omo Nada	7º36’12.46312'N,37º13’35.3807'E	Nada Sokote	Non Functional
Omo Nada	7º36’10.5642'N,37º13’39.35705'E	Nada Sokote	Non Functional
Omo Nada	7º35.4586'N,37º12.8264'E	Nada Dawe	Functional
Omo Nada	7º35.4589'N,37º12.8271'E	Nada Dawe	Non Functional
Omo Nada	7º35.4589'N,37º12.8271'E	Nada Dawe	Non Functional
Omo Nada	7º34.8000'N,37º12.3949'E	Nada Dawe	Functional
Omo Nada	7º35.1382'N,37º14.0181'E	Nada Dawe	Non Functional
Omo Nada	7º35’58.10504'N,37º14’25.58472'E	Nada Dawe	Non Functional
Omo Nada	7º34'58.044'N,37º14’21.5998'E	Nada Dawe	Non Functional
Omo Nada	7º34.7986'N,37º12.3799'E	Nada Dawe	Functional
Omo Nada	7º34.7986'N,37º12.3799'E	Nada Dawe	Non Functional
Omo Nada	7º35’12.5886'N,37º12.7269'E	Nada bidaru	Functional
Omo Nada	7º35.5974’'N,37º12.9353'E	Nada bidaru	Non Functional
Omo Nada	7º35.5974’'N,37º12.9353'E	Nada bidaru	Non Functional
Omo Nada	7º37.0143'N,37º13.4024'E	Nada chala	Functional
Omo Nada	7º36'57.7065'N,37º17.51484”	Nada chala	Functional
Omo Nada	7º36'57.65328'N,37º17.56704'E	Nada chala	Non Functional
Omo Nada	7º36'55.431'N,37º13'15.915'E	Nada chala	Functional
Omo Nada	7º36'55.431'N,37º13'15.915'E	Nada chala	Functional
Omo Nada	7º36'55.431'N,37º13'15.915'E	Nada chala	Functional
Omo Nada	7º37'1.04059'N,37º13'22.8086'E	Nada chala	Functional
Omo Nada	7º36'55.431'N,37º15.915'E	Nada chala	Non Functional
Omo Nada	7º36'59.913'N,37º13'20.6626'E	Nada chala	Functional
Omo Nada	7º36'55.9108'N,37º13'15.71988'E	Nada chala	Functional
Omo Nada	7º36'55.9108'N,37º13'15.71988'E	Nada chala	Non Functional
Omo Nada	7º36'54.66096'N,37º13'14.97396'E	Nada chala	Functional
Omo Nada	7º36'55.886'N,37º13'15.6576'E	Nada chala	Functional
Omo Nada	7º36'53.7318'N,37º13'17.51388'E	Nada chala	Functional
Omo Nada	7º36'53.7318'N,37º13'17.51388'E	Nada chala	Functional
Omo Nada	7º36'55.881'N,37º13'15.64896'E	Nada chala	Non Functional
Omo Nada	7º36'59.632'N,37º13'20.925'E	Nada chala	Non Functional
Omo Nada	7º36'10.4496',37º13'23.8185'E	Nada chala	Non Functional
Omo Nada	7º37'11.4586'N,37º13'23.8078'E	Nada chala	Non Functional
Omo Nada	7º36'57.7065'N,37º13'14.6484'E	Nada chala	Functional
Omo Nada	7º36’53.67852'N,37º13'15.35304'E	Nada chala	Functional

Omo Nada	7º36’53.67852'N,37º13'15.35304'E	Nada chala	Non Functional
Omo Nada	7º35'47.893'N,37º12.3367'E	Nada Dawe	Functional
Omo Nada	7º37'16.6854'N,37º14'48.20604'E	Nada Sokote	Functional
Omo Nada	7º37'16.67676'N,37º14'48.19776'E	Nada Sokote	Functional
Omo Nada	7º37'16.67676'N,37º14'48.19776'E	Nada Sokote	Non Functional
Omo Nada	7º37'23.68272'N,37º14'40.97508'E	Nada Sokote	Non Functional
Omo Nada	7º36'29.5388'N,37º13’43.1286'E	Nada Sokote	Functional
Omo Nada	7º36'29.5368'N,37º13’43.2275'E	Lafteka	Functional
Omo Nada	7º45.2298'N,37º12.6852'E	Lafteka	Functional
Omo Nada	7º43.3152'N,37º12.7269'E	Nano Bonaya	Functional
Omo Nada	7º37'11.4586'N,37º13'23.8078'E	Nada chala	Functional
Omo Nada	7º34'53.9278'N,37º14'1.13172'E	Nada Dawe	Non Functional
Omo Nada	7º36.3118'N,37º12.6509' E	Nada chala	Functional
Omo Nada	7º36.3118'N,37º12.6509' E	Nada chala	Functional
Omo Nada	7º36.3118'N,37º12.6509' E	Nada chala	Functional
Omo Nada	7º36.3118'N,37º12.6509' E	Nada chala	Functional
Omo Nada	7º32.9122'N,37º03.619'E	Nano Bonaya	Functional
Omo Nada	7º32.9122'N,37º03.619'E	Nano Bonaya	Functional
Omo Nada	7º32.9122'N,37º03.619'E	Nano Bonaya	Functional
Omo Nada	7º32.9122'N,37º03.619'E	Nano Bonaya	Functional
Omo Nada	7º33.7953'N,37º04.0894'E	Jato Abe	Functional
Omo Nada	7º33.7953'N,37º04.0894'E	Jato Abe	Functional
Omo Nada	7º37.3349'N,37º09.2205'E	Toli Beyem	Functional
Omo Nada	7º37.3349'N,37º09.2205'E	Toli Beyem	Functional
Omo Nada	7º37.3349'N,37º09.2205'E	Toli Beyem	Functional
Omo Nada	7º45'51.7274'N,37º17'7.2139'E	Toli Beyem	Functional
Omo Nada	7º33.8128'N,37º04.0275'E	Jato Abe	Functional
Omo Nada	7º33.8128'N,37º04.0275'E	Jato Abe	Functional
Omo Nada	7º33.8128'N,37º04.0275'E	Jato Abe	Functional
Omo Nada	7º33.8128'N,37º04.0275'E	Jato Abe	Functional
Omo Nada	7º34.734'N,37º07.904'E	Toli Beyem	Functional
Omo Nada	7º34.734'N,37º07.904'E	Toli Beyem	Functional
Omo Nada	7º39.218'N,37º10.442'E	Toli Beyem	Functional
Omo Nada	7º37'24.04236"N,37º14'42.55404'E	Toli Beyem	Functional
Omo Nada	7º35.3567'N,37º12.0275' E	Toli Beyem	Functional
Omo Nada	7º35.3567'N,37º12.0275' E	Toli sabata	Functional
Omo Nada	7º35.3567'N,37º12.0275' E	Biso Gombo	Functional

Omo Nada	7º45'51.72744'N,37º17'7.21392'E	Doyo Yaya	Non Functional
Omo Nada	7º37'23.67582'N,37º14'40.977508'E	Biso Gombo	Functional
Nadhi Gibe	8º03.7687'N,37º13.0490' E	Kenani	Functional
Nadhi Gibe	7º55.6925'N,37º17.0065' E	Tubssena	Functional
Nadhi Gibe	7º55.4365'N,37º17.0145' E	Raga siba	Functional
Nadhi Gibe	8º03.8994'N,37º13.5793' E	Jato	Functional
Nadhi Gibe	7º34’53.9278'N,37º14’1.13172'E	Dacha Nadhi	Non Functional
Nadhi Gibe	7º34’53.5267'N,37º14’1.2541'E	Raga siba	Functional
Nadhi Gibe	7º56.0128'N,37º13.8382'E	Raga siba	Functional
Nadhi Gibe	7º34’53.6378'N 37º14’1.2215'E	Micha	Non Functional
Nadhi Gibe	7º51'17.84016'N,37º13'52.12884'E	Dimtu	Non Functional
Shabe Sombo	7º29.7168'N,36º29.9574'E	Hallo sabaqa	Functional
Shabe Sombo	7º33.5712'N,36º37.3965'E	Atiro gafare	Functional
Shabe Sombo	7º32.4246'N,36º36.9706'E	sombo daru	Functional
Shabe Sombo	7º32.4246'N,36º36.9706'E	sombo daru	Functional
Shabe Sombo	7º33.1841'N,36º37.3915'E	Atiro gafare	Non Functional
Shabe Sombo	7º33.7128'N,36º37.2292'E	Atiro gafare	Functional
Shabe Sombo	7º28.7330'N,36º25.1299'E	Kishe	Functional
Shabe Sombo	7º33.2923'N,36º36.7426'E	Laku migira	Non Functional
Shabe Sombo	7º33.4338'N,36º36.5672'E	Laku migira	Non Functional
Shabe Sombo	7º31.1439'N,36º31.8274'E	Sabaka Dabiye	Functional
Shabe Sombo	7º33.3429'N,36º36.7748'E	Laku migira	Functional
Shabe Sombo	7º33.8307'N,36º37.6469'E	Aanja	Functional
Shabe Sombo	7º33.4052'N,36º37.2890'E	Aanja	Functional
Shabe Sombo	7º33.2923'N,36º36.7426'E	Aanja	Functional
Sokoru	7º43.7791'N,37º23.0569'E	Yabbu	Non Functional
Sokoru	7º45.5534'N,37º23.9025'E	Maraara	Non Functional

Annex III: The Detail Fish Length and Weight Recording Format

ID	Name of pond fish farmer/Microenterprises	Coordination's of the pond site	District	Kebele	Specific area	Area of pond (m²)	Depth o	Fish Spp.	SF	PM	Source of water	Length (cm)	Weight (Kg)
1	Tura a/Nega A/Sura	7º33.8273'N,37º04.0238' E	Omo Nada	Jato Abe	chafe bali	10mx20m	1.5	Tilapia	RC	Yes	Spring	8.0	10.5
01	Tura a/Nega A/Sura	7º33.8273'N,37º04.0238' E	Omo Nada	Jato Abe	Chafe bali	6m x7m	1.2	Tilapia	RC	Yes	Spring	30.5	171.5
02	Alemayehu kinfu zeleke	7º45.2092'N,37º11.5239'E	Omo Nada	waktola	Gibe	10mx20m	2	Tilapia	RC	Yes	River/stream	26.3	125.2
02A	Alemayehu kinfu zeleke	7º45.2092'N,37º11.5239'E	Omo Nada	Waktola	Gibe	10mx20m	2	Tilapia	RC	Yes	River/stream	25.5	112
02B	Alemayehu kinfu zeleke	7º45.20925'N,37º11.5239'E	Omo Nada	Waktola	Gibe	10mx20m	2	Tilapia	RC	Yes	River/stream	23.5	95
02C	Alemayehu kinfu zeleke	7º45.20925'N,37º11.5239'E	Omo Nada	Waktola	Gibe	10mx20m	2	Tilapia	RC	Yes	River/stream	22.3	81
02D	Alemayehu kinfu zeleke	7º45.20925'N,37º11.5239'E	Omo Nada	Waktola	Gibe	4mx5m	2	Tilapia	RC	Yes	River/stream	20.0	50
03	Rida Haji A/gojam	7º36.8013'N,37º08.1587'E	Omo Nada	Toli beyem	sombo	20mx20	2	Tilapia	TFP	Yes	Spring	19.3	45
04	A/Tamam A/Diga A/Roge	8º03.7687'N,37º13.0490' E	Nadhi Gibe	Kenani	Suye	6mx8m	1.2	Tilapia	GGR	No	Spring	18.1	42
14A	A/Naga A/Gissa A/Godu	7º36.5841'N,37º13.7599'E	Omo Nada	Nada Sokote	sokote	10mx15m	1.1	Tilapia	RC	Yes	River/stream	32.8	210
14B	A/Naga A/Gissa A/Godu	7º36.5841'N,37º13.7599'E	Omo Nada	Nada Sokote	sokote	10mx15m	1.1	Tilapia	RC	Yes	River/stream	32.2	195.6
15	Abdusamad A/JebelA/garo	7º36.0612'N,37º13.7005'E	Omo Nada	Nada Sokote	sokote	8mx9m	1	Tilapia	RC	Yes	River/stream	31.5	180.5
16	A/Tamam A/Bor A/jobir	7º37.4675'N,37º14.5100'E	Omo Nada	Nada Sokote	Daraba	8mx8m	1	Tilapia	RC	Yes	River/stream	9.0	11.3
17	Nazif She jamal A/simal	7º37.4210'N,37º14.6529'E	Omo Nada	Nada Sokote	Daraba	9mx8m	1	Tilapia	RC	yes	River/stream	9.2	14.5
18	Naji A/mecha A/milki	7º36.0863'N,37º13.6747'E	Omo Nada	Nada Sokote	sokote	8mx10m	1.2	Tilapia	RC	yes	River/stream	13.8	16
23	Sufi A/Garo	7º36'29.6385'N,37º13'43.1184'E	Omo Nada	Nada Sokote	sokote	8m x10m	0.8	Tilapia	TFP	yes	River/stream	14.5	25.5
27	Abba Naim AbbaDura	7º36'10.3764'N,37º13'37.72319'E	Omo Nada	Nada Sokote	sokote	9mx10m	0.9	Tilapia	RC	yes	Spring	15.5	26.4
30	Biya A/Gumbul A/Gera	7º36'12.7699'N,37º13'35.8626'E	Omo Nada	Nada Sokote	sokote	8mx8m	1.3	Tilapia	TFP	yes	River/stream	31.0	170.5
36	Naga A/mecha A/Galan	7º35.4586'N,37º12.8264'E	Omo Nada	Nada Dawe	Adiya	10mx20m	1	Tilapia	RC	yes	River/stream	28.5	155.2
42	She Ahmad A/bor	7º34.7986'N,37º12.3799'E	Omo Nada	Nada Dawe	Milmilo	7m x6m	1.2	Tilapia	RC	yes	River/stream	28.0	140
43	A/Raya A/Mecha	7º35'12.5886'N,37º12.7269'E	Omo Nada	Nada bidaru	Dibora	8mx8m	1	Tilapia	TFP	yes	River/stream	28.0	141
45	Latifa A/Raya	7º37.0143'N,37º13.4024'E	Omo Nada	Nada chala	sombo	8mx14m	1.3	Tilapia	TFP	yes	River/stream	27.8	139.7
46	A /Rashad A/mecha A/Fita	7º36'57.7065'N,37º17.51484"	Omo Nada	Nada chala	Sombo	10mx15m	1	Tilapia	RC	yes	River/stream	27.5	135.5
47A	Suhahib A/Jemal A/Mecha	7º36'55.431'N,37º13'15.915'E	Omo Nada	Nada chala	Sombo	10mx15m	1.2	Tilapia	RC	yes	River/stream	26.8	127.3
47B	Suhahib A/Jemal A/Mecha	7º36'55.431'N,37º13'15.915'E	Omo Nada	Nada chala	Sombo	10mx15m	1.1	Tilapia	RC	yes	River/stream	26.0	117.5
47C	Suhahib A/Jemal A/Mecha	7º36'55.431'N,37º13'15.915'E	Omo Nada	Nada chala	Sombo	8mx10m	1.2	Tilapia	RC	yes	River/stream	25.7	115.1
48	A/Jemal A/mecha A/Fita	7º37'1.04059'N,37º13'22.8086'E	Omo Nada	Nada chala	Sombo	8mx10m	1	Tilapia	RC	yes	River/stream	15.6	26.9
50	Miftahi&Amin A/Gidi	7º36'59.913'N,37º13'20.6626'E	Omo Nada	Nada chala	Sombo	8m x15m	1.1	Tilapia	RC	yes	River/stream	16.0	27.5
51	A/jihad A/milki sheki	7º36'55.9108'N,37º13'15.71988'E	Omo Nada	Nada chala	Jarso	8m x8m	0.8	Tilapia	RC	no	River/stream	16.1	28
52	A /Raya A/Fita A/Milki	7º36'54.66096'N,37º13'14.97396'E	Omo Nada	Nada chala	Jarso	8mx10m	1	Tilapia	RC	yes	River/stream	16.3	29
53	A/zinab A/gojam A/morki	7º36'55.886'N,37º13'15.6576'E	Omo Nada	Nada chala	Jarso	8mx10m	0.8	Tilapia	RC	yes	River/stream	25.0	110.9
54A	Miftahi Awel A/raya	7º36'53.7318'N,37º13'17.51388'E	Omo Nada	Nada chala	Jarso	10x15m	1.3	Tilapia	RC	yes	River/stream	25.0	111.2
54B	Miftahi Awel A/raya	7º36'53.7318'N,37º13'17.51388'E	Omo Nada	Nada chala	Jarso	8mx10	1	Tilapia	RC	yes	River/stream	24.6	107
59	A/Rashad A/Foggi	7º36'57.7065'N,37º13'14.6484'E	Omo Nada	Nada chala	Jarso	8mx10m	0.85	Tilapia	RC	yes	River/stream	24.5	104
60	Kalid A/mecha A/Fogi	7º29.7168'N,36º29.9574'E	S/ Sombo	Hallo sabaqa	Wanja Rasi	7mx10m	0.8	Tilapia	TFP	no	River/stream	24.3	103.5
61	Haji Ahimad A/Fogi	7º33.5712'N,36º37.3965'E	S/Sombo	Atiro gafare	Itaya	10mx20m	2	Tilapia	RC	yes	River/stream	24.0	101.8
62	Kadir A/Fogi A/Diga	7º32.4246'N,36º36.9706'E	S/Sombo	sombo daru	Kolle	10mx13m	1	Tilapia	RC	yes	River/stream	24.0	102.1
64	A/Biya A/mecha A/Bulgu	7º33.7128'N,36º37.2292'E	S/Sombo	Atiro gafare	Itaya	10mx15m	2	Tilapia	RC	yes	River/stream	23.1	91

65	Fikadu Gabre Ambo	7º28.7330'N,36º25.1299'E	S/Sombo	Kishe	Bomba safar	10mx15m	1.2	Tilapia	TFP	yes	Spring	23.0	89.8
82	Xahir A/Bulgu	7º37'16.6854'N,37º14'48.20604'E	Omo Nada	Nada Sokote	Daraba	10mx20m	1.2	Tilapia	TFP	Yes	River/stream	22.0	79
83	Mahmed awel A/bulgu	7º37'16.67676'N,37º14'48.19776'E	Omo Nada	Nada Sokote	Daraba	10mx15m	1	Tilapia	TFP	yes	River/stream	22.0	79.3
87	Mahmedsani Abba Rayya	7º36'29.5368'N,37º13'43.2275'E	Omo Nada	Lafteka		8m x10m	1.15	Tilapia	TFP	yes	River/stream	21.9	72
88	Jabal A/Dilbi	7º45.2298'N,37º12.6852'E	Omo Nada	Lafteka		8m x10m	1.1	Tilapia	TFP	yes	River/stream	21.7	66
89	Abbafaji Abba godu	7º43.3152'N,37º12.7269'E	Omo Nada	Nano Bonaya	bonaya	10mx10m	1.2	Tilapia	TFP	yes	Spring	21.5	65
93	Jemila Hawi Abba Biyya	7º37'11.4586'N,37º13'23.8078'E	Omo Nada	Nada chala	Waji	10mx20m	1.3	Tilapia	RC	yes	River/stream	21.0	58
1AA	Gudeta bula cooperative	7º36.3118'N,37º12.6509' E	Omo Nada	Nada chala	Samecha	10mx20m	1.2	Tilapia	RC	yes	River/stream	20.5	53
1AB	Gudeta bula cooperative	7º36.3118'N,37º12.6509' E	Omo Nada	Nada chala	Samecha	10mx20m	1.2	Tilapia	RC	yes	River/stream	20.5	56.1
1AC	Gudeta bula cooperative	7º36.3118'N,37º12.6509' E	Omo Nada	Nada chala	Samecha	10mx20m	1.2	Tilapia	RC	yes	River/stream	20.3	51
1AD	Gudeta bula cooperative	7º36.3118'N,37º12.6509' E	Omo Nada	Nada chala	Samecha	10mx20m	1.2	Tilapia	RC	yes	River/stream	19.8	49
2BA	Abdi gudina cooperative	7º32.9122'N,37º03.619'E	Omo Nada	Nano Bonaya	Chafe toli	10mx20m	1	Tilapia	RC	yes	River/stream	19.6	46.7
2BB	Abdi gudina cooperative	7º32.9122'N,37º03.619'E	Omo Nada	Nano Bonaya	Chafe toli	10mx20m	1	Tilapia	RC	yes	River/stream	19.6	47
2BC	Abdi gudina cooperative	7º32.9122'N,37º03.619'E	Omo Nada	Nano Bonaya	Chafe toli	10mx20m	1	Tilapia	RC	yes	River/stream	19.5	44
3	Chafe gode cooperative	7º33.7953'N,37º04.0894'E	Omo Nada	Jato Abe	Chafe bali	8mx8	1	Tilapia	Rivers	yes	River/stream	19.5	46
4	Hulle 1st Cooperatives	7º37.3349'N,37º09.2205'E	Omo Nada	Toli Beyem	Hulle	10mx20m	1.2	Tilapia	RC	yes	Spring	19.2	44.1
5	Hulle 2nd cooperatives	7º45'51.7274'N,37º17'7.2139'E	Omo Nada	Toli Beyem	Hulle	10mx20m	1.35	Tilapia	RC	yes	Borehole	19.0	43.4
6	Chafe Bali cooperative	7º33.8128'N,37º04.0275'E	Omo Nada	Jato Abe	Chafe bali	10mx20m	1.2	Tilapia	RC	yes	Spring	18.2	43
7C	Ifa Boru Cooperatives	7º34.734'N,37º07.904'E	Omo Nada	Toli Beyem	Chafe bali	10mx20m	1.2	Tilapia	RC	yes	Spring	17.8	40
7D	Ifa Boru Cooperatives	7º34.734'N,37º07.904'E	Omo Nada	Toli Beyem	Chafe bali	10mx20m	1.2	Tilapia	RC	yes	Spring	17.2	34
14	Chayina kamp	7º37'23.67582'N,37º14'40.97751'E	Omo Nada	Biso Gombo	Eloda	10mx20m	2	Tilapia	RC	yes	Ground	16.4	30.5

TFP=Transfer from pond, RC=Research centers, S/Sombo=Shabe Sombo, GGR=Gilgel Gibe Reservior, SF= Source of fingerling, PM=Pond Management