UNIVERSITY OF KWAZULU-NATAL

FINANCIAL VIABILITY OF BIOMASS PRODUCED IN A SMALL-SCALE, LOW-COST AQUAPONIC SYSTEM IN NDWEDWE

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Declaration

I ...Phungula, Mthabiso Lethukuthula................ declare that:

- The research reported in this thesis, except where otherwise indicated, is my original work.

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Abstract

This study sought to determine the financial viability of small-scale, low-cost aquaponic systems in KwaZulu-Natal, particularly a small-scale, low-cost aquaponic system based in a rural homestead in Ndwedwe. The objectives of the study were to ascertain the financial viability of biomass yield (both fish and plants) in a small-scale, low-cost aquaponic system and to determine factors that affect the biomass output of a small-scale, low-cost aquaponic system.

Aquaponics possesses the potential for food security and local economic development, because in aquaponics two enterprises (fish and vegetables) could be developed. However, aquaponics is an emerging practice in South Africa that possesses the potential of creating employment and ensuring household food security. The conventional methods of producing food have been criticised for producing toxic runoff which has had cumulative pollution effects. These effects include; the toxins from artificial fertilizers seeping into water bodies where people and marine life consume the intoxicated water. Conventional farming methods also increase soil run- off which depletes the soil reserves needed for sustainable farming practices. Aquaponics provides an alternative, sustainable method of farming which does not pose a threat to any ecosystems.

On a global scale, it is evident that there is a need for innovative means of food production to address food and nutrition insecurity and the social ills that come with it such as poverty. Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs. Food and nutrition security are measured by four pillars, namely; access, availability, utilization and stability. These four pillars are determinants of food security, they measure whether people have sufficient access to safe and healthy food, and they are the standard by which food and nutrition security is determined. Access, availability, utilization and stability in food security is influenced by numerous factors such as politics, economic stability, location and dietary preferences. Aquaponics could enhance food sovereignty for both food and nutrition security, if implemented in communities, thereby serving all food security pillars.

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DO: Dissolved oxygen
DWC: Deep water Culture
FAO: Food and Agriculture Organization
FCR: Feed conversion rate (kg dry feed consumed per kg wet biomass gained)
LED: Local Economic Development
NFT: Nutrient film technique
NGO: Non-Governmental Organization

NH_3: A compound of nitrogen and hydrogen with the formula NH_3 IIt is a transparent gas with a characteristic pungent smell – Ammonia

NO_3: A polyatomic ion with the molecular formula NO_3 − Nitrates are mainly produced for use as fertilizers in agriculture because of their high solubility and biodegradability – Nitrate

pH: The acidity or alkalinity of a solution. With the value of 7 representing neutrality on the scale.
RAS: Recirculating aquaculture system
TAN: Total ammonia nitrogen
UVI Model: University of the Virgin Isles

CHAPTER ONE: OVERVIEW OF THE STUDY

1.1. Introduction

This chapter will introduce the entire study. The objectives, research questions, hypothesis and dissertation outline will be presented in this chapter. The problem statement will also be presented in this chapter and will guide and justify as to why the study needs to be conducted.

Aquaponics is the production of fish and crops concurrently in a closed system(Mchunu et al., 2018). It is a recirculatory aquaculture system whereby fish waste and fish feed dissolve into ammonia (NH3) and through the microbial process in the system, it is converted into ammonium (NH4) which is consumed by plants. In aquaponics, the dissolved fish waste in water is used as a natural fertilizer material to supply crops with nutrients in hydroponic culture (Kyaw and Ng, 2017), all implemented sustainably in a symbiotic nature.

Aquaponics possess the potential for food security and local economic development, because in aquaponics two enterprises (fish and vegetables) are involved. However, aquaponics has not been studied extensively, particularly in small-scale, low-cost scales. Small-scale, low-cost operations have the potential to promote economic development with related employment generation, which South Africa currently needs (Rizal et al., 2018). The conventional methods of producing food have been criticised for producing toxic runoff which has cumulative pollution effects such as; the toxins from artificial fertilizers seeping into water bodies where people and marine life consume the intoxicated water. Conventional farming methods also increase soil run-off which depletes the soil reserves needed for sustainable farming practices (Maucieri et al., 2018).

On a global scale, it is evident that there is a need for innovative means of food production to address food insecurity and the social ills that come with it such as unemployment and poverty. Food security is when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs (Delgadillo-Díaz et al., 2019). Food and nutrition security are measured by four pillars, namely, access, availability, utilization and stability (Delgadillo-Díaz et al., 2019). These four pillars are determinants of food security, they measure whether people have sufficient access to safe and healthy food, and they are the standard by which food security is determined. Access, availability, utilization and stability in food security is influenced by numerous factors such as politics, economic stability, location and dietary preferences (Buzby and Lin, 2014). Aquaponics could enhance food sovereignty for food and nutrition security, if implemented in food insecure communities (Bush and Oosterveer, 2019) , thereby serving all food security pillars. As such, social enterprise development through aquaponics has the potential for sustainable economic development and food insecurity.

The traditional methods of addressing food insecurity have been farming revolutions such as the green revolution (Pingali, 2012). This revolution took place in the mid twentieth century with the intention of increasing crop yields for the purpose of self-sustenance and economic growth in the developing world. Food aid is another traditional method that has been used around the world and is still being used to address food insecurity. However, the efficacy of traditional methods of addressing food insecurity are gradually being challenged and improved. For example, the use of hydroponics. This is an unconventional method of supporting plants artificially using ionic compounds instead of traditional soil (Proksch et al., 2019). With plant growth often being limited by climatic and soil conditions, farmers use hydroponics to grow plants in a controlled environment where plants are less affected by external factors that could affect their yield (Proksch et al., 2019). This is being practiced globally in countries such as the United States, India, Japan and many more. Subsequent to the hydroponic system innovation, aquaponic systems have been a more sustainable improvement of hydroponics in the sense that aquaponics is a circular system that uses fish excrements as fertiliser for growing crops concurrently (Pecl et al., 2017).

1.2. Motivation for the Study

Aquaponics is an emerging practice and holds significant potential for sustainable food production in urban and rural areas. As such, aquaponics also holds a research niche where studies could be conducted to develop low-cost aquaponic systems for small-scale farmers (Mlambo and Mapiye, 2015). These cost-efficient systems are suitable solutions for rural communities and determining the financial viability of the biomass output is essential to aquaponics as this assists the farmer in assessing the potential to commercialise or not.

Kwa-Zulu Natal is no exception in facing food insecurity because of factors such as; climate, food distribution and food access. Nearly 14,3 million South Africans are affected by food insecurity, of which most of them are children, women and the elderly (Mlambo and Mapiye, 2015). Moreover, prices of staple such as wheat and maize has been increased in South Africa (Abdu-Raheem and Worth, 2011). As such, households now face more difficulties in buying food items resulting in food insecurities, particularly in landless and female-headed households (Abdu-Raheem and Worth, 2011).

Although aquaponics is currently in the pilot phases, it has the potential to be a key player in economic growth on a local and global scale. A provincial survey that was conducted by (Mchunu et al., 2018) is evidence of the current state of aquaponics in the KwaZulu Natal (KZN) province and it indicates that aquaponics is an emerging practice that is succeeding in addressing household food security and also has potential to contribute to the local economic development in KZN. However, it is not without challenges, the main one being unfavourable climate conditions. Favourable climate conditions are highly imperative in gaining success in aquaponics. This is due to aquaponics having plant and fish components which rely on warm temperatures for growth and survival (Miličić et al., 2017).

Methods that are currently being used to address food insecurity in KZN include; food aid in the form of food banks, farming aid in the form of distribution of seeds to assist subsistent farmers. This is good; however, it is not sustainable and has the potential to be crippling in the sense that recipients of food aid develop a dependency on the aider and do not explore innovative ways to sustain themselves (McGuire, 2015). Hence, this perpetuates the poverty cycle. Aquaponics is a means of empowering communities, as suggested by (Mchunu et al., 2018), to get involved in being the solution to their own food insecurity needs, this encourages independence and self-sustenance from communities who would have otherwise continued being dependant on aid.

It is vital that aquaponics is not only efficient in circulating nutrients in the system but also in producing good quality food that is nutritious and edible. The food output in an aquaponic system is important as it fulfils the purpose of the system. The food output will be that of fish and plants (which can be categorised as leafy or fruity). Albeit, the system functions concurrently, however the food harvesting is not simultaneous. The fish biomass is harvested at a different time than the plant biomass. The main factors to consider in the food output in an aquaponic system are; food yield, food quality, food type and the market value. There are numerous factors such as climate conditions and location that influence the type of vegetation one plants at what time of the year and an aquaponic system is not exempt from such conditions therefore it is imperative that the food output in an aquaponics system be assessed and monitored for quality, yield and growth as this will determine whether aquaponics is financially viable or not.

1.3. Focus of the Study

The quality of food is imperative in determining whether it is edible or not. Therefore, analysing the various factors affecting the financial viability of biomass output (fish and plants) in an aquaponics system is necessary as this will determine whether aquaponics is a success or failure, whether it is marketable or not and whether it has potential to be commercialised or not. As a result, this study will focus on analysing the financial viability of the biomass output produced in a small-scale, low-cost aquaponic system as this is key to calculating whether the system will succeed or fail. Without determining the financial viability of the biomass produced in a small-scale, low-cost aquaponics system, small-scale farmers will not know whether they are making a loss or profit with their aquaponics systems and this vital in determining whether small-scale farmers can expand beyond their household needs into businessmen. An aquaponic system entails the concurrent growth of fish and plants in a closed system whereby nutrients are circulated (Manning et al., 2013). The whole aim of an aquaponic system is to produce fish and plant biomass sustainably, the central focus being on the food output whilst keeping the nutrients balanced and stable in the system.

1.4. Research Problem

In the past decades numerous solutions such as household gardens, feeding schemes and other forms of food aid (Hart et al., 2013) have been implemented toward addressing food security. However, food security remains an area that constantly requires innovative and relevant means of finding sustainable solutions. Aquaponics could potentially be the most feasible, financially viable, sustainable response to household food insecurity both in rural and urban communities, as shown by (Love et al., 2015b) Economically, aquaponics systems can be modified to be low-cost yet yield intensively, provided the system is constructed and maintained correctly. Like every phenomenon, there are limitations that have emerged as communities continue to experiment with aquaponics as a solution to household food security. The following are some of the limitations and challenges that the implementation of small-scale, low-cost aquaponics faces;

- Traditionally, some African communities believe that fish or seafood in general could lessen the efficacy of traditional remedies in the body. However, it is questionable as to what is the criteria that determines whether the fish is consumed or not. Freshwater fish or subsistent farmed fish? Most African communities consume canned fish, therefore the terms on which fish is disqualified for consumption are not clear yet. Therefore, a consumer perception study is necessary in determining the success and financial viability of aquaponics (Short et al., 2017).
- Fish is not readily available to all communities. Some communities reside far from water bodies or shops where they can easily access fish.
- Seafood is not the staple diet for most communities in the Kwa-Zulu Natal (KZN) context. Most rural communities in KZN are not aware of the health benefits associated with seafood (Pillay and Kutty, 2005).
- Producing the right fish and crops in favourable locations and climate conditions, this often requires specialised skills and is not general knowledge to all farmers.
- Lack of knowledge and data on whether the biomass output in an aquaponic system is financially viable or not. Determining financial viability is not a practice that is easily known and grasped by everyone, it has to be learnt.

Albeit there are limitations, seafood is a growing industry and the health benefits associated with it are becoming popular. Seafood has become affiliated with health benefits such as Omega 3 Fatty Acids, it is low in fat and therefore reduces obesity, it is high in protein and very low in cholesterol (Wu et al., 2019). Rural communities in KZN might not be as informed on the health benefits associated with seafood and hence why it is not a staple as it is in other African countries such as Mozambique. However, in urban areas it is because they are exposed to wider food varieties including fish which encourages urban residents to consume food they would not normally consume in rural areas (Carruthers, 2015). This is due to urbanisation. Hence, this suggests that food security will continue to be a growing issue both in urban and rural areas in KZN. However, aquaponics could be a solution to food insecurity if communities can be mobilised to learn how to grow food in small-scale, low-cost aquaponic systems.

This study will specifically determine the financial viability of the biomass produced in a small-scale, low-cost aquaponics system. Financial viability is essential to any project because, it minimises risk (AlShrouf, 2017) whereby the inception of a particular project might have commenced only to find that it was not financially viable. Conducting a study on the financial viability of the biomass output in a low-cost aquaponics system is key in contributing to some of the existing research on local economic development and food security and most importantly, assisting small-scale farmers with making informed decisions.

1.5. Aim of the study

- To determine the financial viability of biomass produced in a small-scale, low-cost aquaponics system in Ndwedwe that will promote sustainable agricultural practices, increase food and nutrition security and promote local economic development.

1.6. Objectives of the study

- To determine the biomass production of fish from a small-scale, low-cost aquaponics system.
- To determine the biomass production of plants from a small-scale, low-cost aquaponics system.
- To determine the financial viability of the biomass produced in a small-scale, low-cost aquaponics system.
- To determine factors affecting financial viability in a small-scale, low-cost aquaponics system.

1.7. Research Questions

1. What is the length and weight of fish produced in a low-cost aquaponics system over a period of seventeen weeks?
2. What is the weight and height of plants and fruit produced in a low-cost aquaponics system over a period of seventeen months?

3. What are the cost implications of biomass produced in a small-scale, low-cost aquaponics system?
4. What are the variables that affect financial viability in a small-scale, low-cost aquaponics system?

1.8. Significance of the study

This study aims to find the financial viability of running a low-cost aquaponics system. The expected outcome is that the biomass yield in the low-cost aquaponics system will grow at an accelerated rate compared to biomass produced using conventional farming methods. The biomass in a low-cost aquaponics system will also be of better quality aesthetically in comparison to conventionally produced biomass. This study will conduct a financial viability analysis of low-cost aquaponics systems using an excel model that will generate graphs. The model will be used to capture the direct input costs of both the fish and plant biomass. The acquired costs from seedling to yield will then be compared to the market value of the fish and plant biomass in order to determine the financial viability of low-cost aquaponics systems.

In this study fish and plant biomass will be monitored and measured over a period of seventeen weeks. It is expected that during the seventeen-week period, harvesting will take place and biomass output can be compared to biomass that will be planted conventionally in a low-cost aquaponics system based in a homestead in rural Ndwedwe. The growth will be measured using a scale for the fish and a measuring tape for the plant biomass. Plant biomass will also be planted in a field outside on a field in the same site the same time seedlings will be planted in the low-cost aquaponics system. This is so that a comparison can be made in terms of growth rate and overall performance of the plant yield in the low-cost system and the plant yield grown conventionally. The results of the financial viability analysis will show the potential for sustainable economic development in aquaponics. Aquaponics has the potential for sustainable economic development because, aquaponics is a recirculatory system, hence it saves water whilst producing fish and plant biomass at a quicker rate than conventional farming methods (Becker et al., 2011).

This study is imperative in developing innovative avenues to optimise small-scale, low-cost aquaponics systems. Determining the financial viability of any project is key because, without the knowledge of the costs (fixed, operational and direct) that will be incurred or profited, one cannot conclude whether a project is going to be worthwhile or not (Martin, 2017). Therefore, this study will add invaluable knowledge to the ongoing developments in low-cost aquaponics systems. This study will particularly determine the fixed, operational and direct costs of the yield in a low-cost aquaponics system. The information acquired will assist prospective aquaponics farmers in calculating the approximate costs they will incur to produce the biomass yield in comparison to the biomass yield produced using other farming methods.

1.9. Research Methodology

The study took place in Ndwedwe, which is a rural community situated inland near Wartburg in the Natal Midlands. The study was conducted using a quantitative approach only.

A quantitative approach, if collecting data entails testing objective theories by examining the relationship among variables (Trotter II, 2012). The relationships that will be examined is that of the biomass output in a low-cost system and the financially viability of the biomass output in comparison to conventional farming practices. The plant biomass will be measured in height and its yield at harvesting phase. The fish biomass will be weighed weekly using a random sampling method.

1.10. Outline of dissertation

Chapter one – This chapter focuses on introducing the topic, or the study area, by unpacking the background of the study, research problem statement, aim and objectives of the study, case study area, an overview of the study and methodology.

Chapter two – This is the literature review, which defines the concepts and theories of the study, presents existing information based on the topic, policies framework and other case studies.

Chapter three – This chapter discusses the research methodology, which comprises of the quantitative approach, sampling criteria, questionnaires, primary and secondary data, and data collected from farmers and farm managers.

Chapter four – This chapter presents and discusses the analysis of the results and findings; data collected from the open-ended and closed-ended questions, and rich information extracted from farmers.

Chapter five – The chapter presents a summary of the findings of the research and gives recommendations on how future farmers can improve.

1.11. Chapter Summary

To conclude, this chapter introduced the topic of this study and lay out the direction in which the study intends to go in terms of working out whether the biomass output in a low-cost aquaponic system is financially viable or not. Aquaponics is a sustainable agricultural practice that addresses food security and climate change, however, this chapter focused on introducing the topic.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

This chapter will focus on the literature basis for this study. The literature base will address the questions of why this study is important and what other scholars have found on the financial viability of the biomass produced in a, small-scale, low-cost aquaponic system. The literature will be arranged according to themes as this will later assist in reporting the findings of the study and making necessary comparisons and correlations. The literature will address the objectives and research questions of the study and guide the study in such a way that it addresses the existing knowledge gap in the financial viability of the biomass output in small-scale, low-cost aquaponic systems.

Aquaponics is an emerging practice in the African continent, with most people that are practicing it being based in South Africa. Africa is among the most poverty-stricken continents and therefore is not exempt from the reality of food insecurity. The popular methods of remedying food insecurity in Africa is food aid coming from developed nations, with over 29 African countries depending on food aid and continuing to remain in a state of being food insecure (Sheahan and Barrett, 2017). Among those countries relying on food aid are Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Democratic

Republic of the Congo and many more (Aguilara-Titus et al., 2014) . There is a need for unconventional ways of producing food and ensuring household food security, aquaponics is a possible solution.

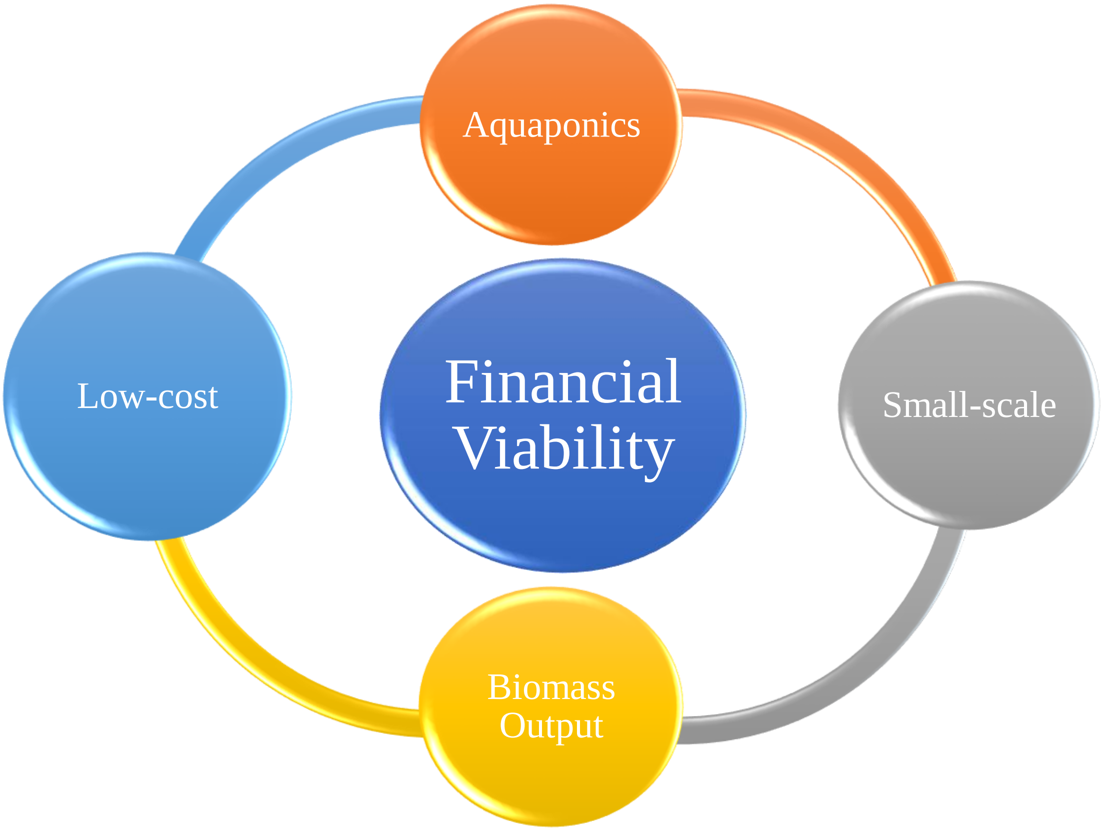
The alternative, unconventional practice of aquaponics can prove to be an important solution to a country like South Africa that has limited agricultural production resources (water and fertile croplands), high urbanisation rate and exponentially increasing urban poverty (Jones, 2002). Aquaponics can provide good quality food diversity (protein and greens) for rural and urban areas. In addition to food production, aquaponics can play a critical role in having a holistic approach to environmental sustainability. Being a closed system, aquaponics does not have surface run-off which has proven to possess hazardous contaminants due to toxic pesticides (Munguia-Fragozo et al., 2015). Aquaponics has the potential to contribute significantly to sustainable, organic food production. Aquaponics, albeit debatable, is deemed organic as the biomass output can be famed organically depending on the farmer. Some farmers do make use of fertilizers but it is not advisable to chemically edify the system because of the complex nutrient cycle pertaining to aquaponics (Sace and Fitzsimmons, 2013).

Aquaponics has the potential for community development. Aquaponics being a complex system as suggested by (Palm et al., 2018), could bring communities together to find multi-faceted solutions to social issues such as food insecurity and sustainable farming practices. This study seeks to explore the food output of an aquaponics system for the purpose of determining the market value of the food produced, analysing the nutritional value and exploring low-cost models that could yield optimum produce in order to ensure household food security (Eigenbrod and Gruda, 2015). Aquaponics has the potential to sustainably produce organic food at a lower than usual cost without compromising the quality of the food output.

2.2. Conceptual Framework

This section will present a schematic conceptual framework of the study and the literature base on which the study will expand on.

Figure 1: Conceptual Framework Diagram



Source: Author, 2019

The diagram above indicates that financial viability is the main concept of the study and the sub-concepts are; small-scale, low-cost aquaponics systems. Financial viability will be calculated in the context of the biomass output of a small-scale, low-cost aquaponic system. The literature will seek to address the knowledge gap that currently exists with small-scale, low-cost aquaponic systems. Determining the financial viability of the biomass output of a small-scale, low-cost aquaponics system is key in the study. There are numerous factors that affect financial viability in the biomass output of aquaponics but there is insufficient literature that addresses that gap. This study will late report on the results of factors that affect financial viability, which will address the fourth objective of the study.

2.3. Hydroponics

Hydroponics is more prevalent than aquaponics, and since its implementation over 40 years ago it has become common in commercial greenhouse agriculture. It is often called soilless farming because crops are cultivated in a soilless nutrient solution in these systems. The nutrient solution includes all the vital growth macronutrients and micronutrients that are generally optimally balanced for peak productivity (Sayara et al., 2016). Hydroponic growers can typically take plants to harvest much quicker than growing in soil due to accurate control and optimal circumstances. It is also feasible to have a year-long growing season using greenhouse methods, enabling growers to supply new seasonal produce (AlShrouf, 2017). It is also often asserted that hydroponically cultivated crops are of greater quality and have a better flavour than conventional agriculture (Jones Jr, 2016). Hydroponics is often promoted as an extremely sustainable type of farming and a main method of meeting the fast-growing population of the world's food demand. Besides its rapid crop cycling and prolonged increasing season, its advantages include

- Significant reductions in water usage
- Higher efficiency allowing for more plants per square foot
- No detrimental effects on soil quality
- Reduced use of herbicides and pesticides due to the controlled environment
- Reduced fertilizer requirements compared to conventional agriculture

(Bush and Oosterveer, 2019)

In particular water and space efficiency are two of the most important benefits of the system allowing for food production in urban areas where water and space are both a premium. Hydroponics can reduce water usage between 90 and 97% compared to soil based agriculture (Reyes Lastiri et al., 2018). This is particularly attractive with the high rates of urbanization and population growth. It can also serve to preserve soil quality in areas where poor farming practices have degraded the environment.

One hurdle for hydroponic production is its high capital cost, in particular for the greenhouse and growing system (Jones Jr, 2016). Because its production method is very similar, aquaponics offers all of the benefits of hydroponic production and also shares many of its challenges.

The most common hydroponic systems as suggested by (Suhl et al., 2016) currently being used in aquaponics are the floating raft, nutrient film technique (NFT), and the bench bed hydroponic systems. Floating raft systems are ideally suited for quick-turnaround lettuce crops. Many commercially available NFT systems can handle only small-rooted crops like lettuce because of limited trough volume (4 in. wide x 2 in. deep) (Lucas et al., 2019). Large-rooted vegetables such as tomato, cucumber, pepper, and mint can be grown with NFT provided the trough's root-zone space is large enough (18 in. wide x 4 in. deep) to accommodate the plant roots and allow water to continue flowing down the trough. Properly designed and operated media (perlite, vermiculite, peat, coconut coir, pine bark, pebbles, and combinations) systems such as the bench bed have the broadest crop choices because they can accommodate water-loving plants or plants that need well-drained soils (Diver and Rinehart, 2000). Oftentimes media-filled plastic pots are placed in the bench bed to facilitate crop cycles and make the beds easier to clean and maintain.

Hydroponics is more pervasive than aquaponics and it has turned out to be regular in business nursery farming since its presentation more than 40 years back. It is frequently alluded to as soilless horticulture in light of the fact that in these frameworks plants are developed in a supplement arrangement without soil (Buzby and Lin, 2014). The supplement arrangement contains all the basic macronutrients and micronutrients for development, which are generally ideally adjusted for greatest efficiency. In view of the exact control and ideal conditions hydroponic cultivators can commonly carry yields to reap a lot quicker than developing in soil. It is likewise conceivable to have a yearlong developing season with nursery strategies, enabling cultivators to give newly create out of season (Yep and Zheng, 2019). Too hydroponically developed plants are regularly professed to be of higher calibre and have better taste than customary agribusiness. Hydroponics is frequently advanced as a profoundly economical type of farming and a key strategy for satisfying the nourishment need of the world's quickly developing populace. In expansion to its fast yield cycling and expanded developing season its advantages incorporate such as;

- A Significant decrease in water utilization
- Higher proficiency considering more plants per square foot
- No hindering impacts on soil quality
- Reduced utilization of herbicides and pesticides because of the controlled condition.
- Reduced manure necessities contrasted with traditional horticulture (Carruthers, 2015)

Water and space effectiveness are two of the most significant advantages of the framework taking into consideration nourishment generation in urban regions where water and space are both a premium. Hydroponics can diminish water use somewhere in the range of 90 and 97% contrasted with soil based farming (Cohen et al., 2018). This is especially alluring with the high paces of urbanization and populace development. It can likewise serve to save soil quality in territories where poor cultivating practices have debased nature. One obstacle for hydroponic creation is its high capital expense, specifically for the nursery and developing framework (Walraven, 2014). Since its generation strategy is fundamentally the same as, aquaponics offers the majority of the advantages of hydroponic generation and furthermore shares a large number of its difficulties.

2.3. Aquaculture

Aquaculture is a method of farming that involves farming in a controlled environment whereby factors affecting fish growth are monitored and controlled consistently. Over the past few decades, aquaculture has risen significantly to satisfy increasing seafood demand, as wild catch has remained constant. Approximately 50% of the worldwide fish supply is anticipated to be made available by 2030 (Rakocy et al., 2016). Aquaculture has the commitment to provide the ever-increasing demand for seafood while preserving the fish populations of our ocean. However. Aquaculture concerns the environment and health. Marine aquaculture has been known to produce high levels of organic wastes, eutrophication, and increased nutrient concentrations in surrounding bodies of water. This is a result of high concentrations of fish waste that are an inevitable output of aquaculture (Walraven, 2014).

Aquaculture provides an important source of protein which is fish, Fish accounts for more nutrients and vitamins than other protein sources. Aquaculture is imperative to the famring community as it contributes to more than half of the world’s protein sources (Pillay and Kutty, 2005). Aquaculture, although it relieves the oceans of pressure from over fishing, it has room for improvement in terms of waste water treatment. Waste water is still being discarded irresponsibly in most aquaculture farms which can pose a threat to the environment in the long run as this water excessively rich in nutrients (Nozzi et al., 2018). There are numerous alternatives of discarding the nutrient rich effluent from aquaculture operations. (Cabello et al., 2016) suggests planting plants near the catchment of the wastewater from the aquaculture operations. The most popular use of waste water currently is the start- up aquaponics systems. The aquaponics cycle rotates the nutrients to plants which absorb what they need and filter what they don't need (Ottinger et al., 2016). Aquaculture also relies heavily on fishmeal, which poses a question on the sustainability of aquaculture (Hecht et al., 2006). Aquaculture has the potential to explore sustainable, fish feed alternatives. These alternatives include duckweed which is a natural water plant that fish consume.

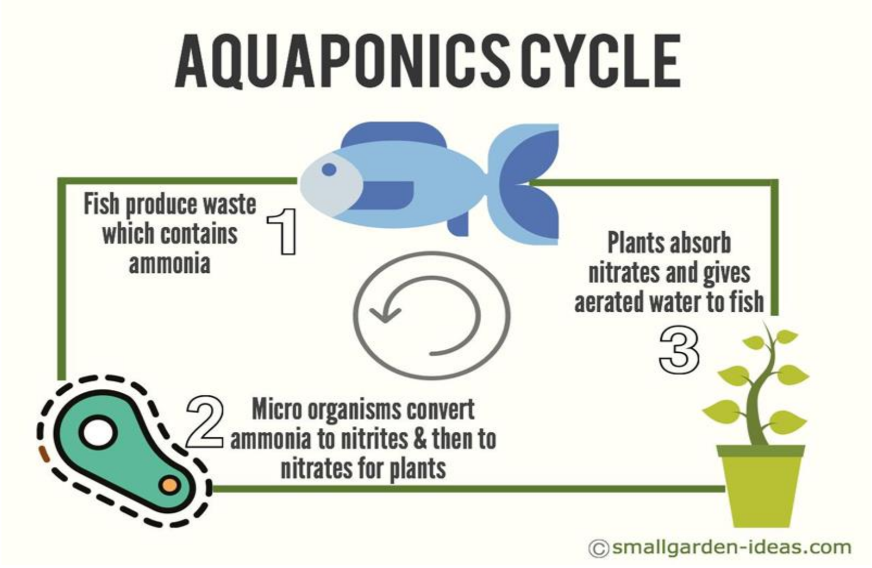
Africa has been surveyed to possess the potential and optimum conditions to farm tilapia. Carp and catfish (Ridler and Hishamunda, 2001). Of which as indicated by (Ridler and Hishamunda, 2001), 15% is viewed as most appropriate, with the potential for yields of up to 2.0 yields/year for Nile tilapia and 1.7 harvests/year for African catfish. Despite the fact that aquaculture has developed exponentially in many areas where the potential exists, it has not done as such in Sub-Saharan Africa. Sub-Saharan Africa's commitment to aquaculture farming is under 1% (Hunter et al., 2017). Aquaculture and aquaponics have more potential in Africa than they do elsewhere, yet more aquaculture farming is taking place on other continents than in Africa. The number of inhabitants in Africa is required to arrive at 1.18 billion by 2010. To look after normal nourishment fish utilization at present degrees of 8 kg for each individual every year, supplies would need to increment from some 6.2 to 9.3 million tons for each year in 2020. To help future needs, catch fisheries should be supported and if conceivable upgraded, and aquaculture grew quickly, to increment by over 260% for example a yearly normal of over 8.3% by 2020 in sub-Saharan Africa alone (Evans et al., 2005), which is fundamentally higher than late levels. In the event that creation from Egypt, the major local maker, progressively constrained via land and water assets (Soto et al., 2008) is prohibited, the development rate for the remainder of the area would must be significantly higher.

Aquaculture is the rearing of fish and other sea life in a controlled and monitored environment(Ottinger et al., 2016). Sea life has evolved over time. Different types of fish species thrive in different environments depending on the geographic location. In aquaculture farming, it is important to grow fish which are suited to the environment where the farm is set up in order for the aquaculture operation to be a success(Shafahi and Woolston, 2014). Various reasons have been recommended for the poor pace of development in aquaculture improvement in the area. These incorporate causes identifying with fish utilization inclinations, the general degree of financial improvement in rustic zones, the arrangement and administration condition, and restricting social components (Asia, 2006) together with a need of access to accessible data .

2.4. Aquaponics

Aquaponics is the sustainable rearing of fish and plant biomass concurrently in a close-loop system (Rakocy et al., 2016). The fish waste is broken down with the help of beneficial bacteria in the system. Aquaponics, albeit may appear as water intensive at first, in the long run it is actually more sustainable than conventional farming methods because, not only can the water be harvested from the rain but it is also a recirculatory system, which means the water rotates in the system (Béné et al., 2016). Waste water would only occur if the system was under stress and the system needed to be flushed. Given the system is well-balancede and well maintained, there should be no need to flush it, hence the water would recirculate as aquaponics is a recirculatory aquaculture system (RAS). When compared to other soilless systems (Blidariu and Grozea, 2011), aquaponics requires the least supplement buffering compared to farming practices like hydroponics which require an extensive range of supplements in order to function. Below is a figure of the aquaponics cycle, depicting how the nutrients from fish waste are broken down by bacteria and consumed and filtered by plants, then making their way back to the fish.

Figure 2: Diagram of aquaponics cycle



Source: (Al- Hafedh et al., 2008)

The fish waste, which includes ammonia excreted by the gills and solid waste, are broken down and oxidized into nitrate before the plants can absorb the nutrients. The decomposition is called mineralization and is carried out by two types of beneficial bacteria, *Nitrosomonas* *sp.* and *Nitrobacter sp*., which convert the toxic ammonia into nitrite, and nitrite to nitrate, respectively ((Blidariu and Grozea, 2011);(Graber and Junge, 2009). Compared to soil agriculture, where generally less than 1% of the total water consumption is absorbed by plants, aquaponic systems continuously recirculate the water to the plants(Manning et al., 2013)). Aquaponics is also a land saving approach since they could be built in buildings or on rooftops (Bush and Oosterveer, 2019). In addition to saving water and land, aquaponic systems are also pesticide-free and therapeutant-free. Pesticides are toxic to fish while most therapeutants, such as antibiotics for treating fish parasites, may harm beneficial bacteria and can be absorbed by the plants (Çimrin et al., 2010). Although different systems may vary tremendously, according to some model studies, aquaponics can generate a yield comparable to that of hydroponics and soil agriculture(Liang and Chien, 2013). There are very few studies analyze the economic aspects of aquaponic systems, the statistics on energy consumption are not available. According to one study on economic analysis of aquaponic systems by Rakocy and Bailey, aquaponic systems require “moderate energy input” but no quantitative energy consumption information is available (Rakocy et al., 2003)

Aquaponics has the potential for community development. Aquaponics being a complex system as suggested by (König et al., 2018), could bring communities together to find multi-faceted solutions to social issues such as food insecurity and sustainable farming practices. This study seeks to explore the food output of an aquaponics system for the purpose of determining the market value of the food produced, analysing the nutritional value and exploring low-cost models that could yield optimum produce in order to ensure household food security. Aquaponics has the potential to sustainably produce organic food at a lower than usual cost without compromising the quality of the food output.

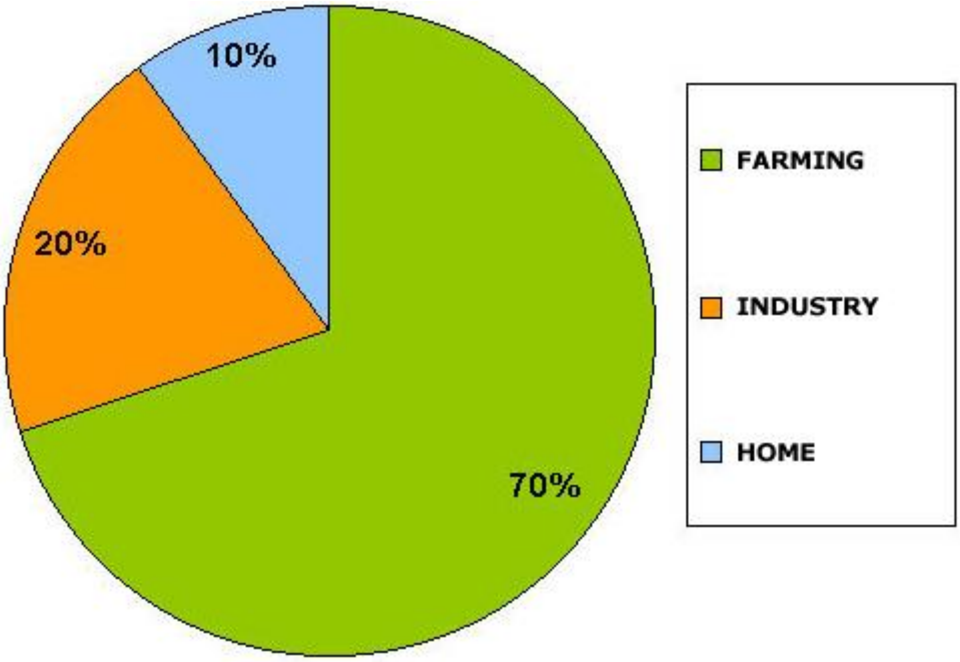
It is imperative to consider that although aquaponics is known to be a combination of two components (aquaculture and hydroponics), there is a third bacterial component which is crucial for the functioning of any aquaponics system. The bacterial component drives the nitrification process.(Rakocy et al., 2016, Love et al., 2014). This process entails the conversion of nitrites into nitrates which are necessary for the uptake of the plants in the hydroponic component in aquaponics.

Water is crucial to the success of aquaponics as it is to other conventional farming practices (Rafiee and Saad, 2005). However, in aquaponics it is the water quality that is most crucial as it is a closed- loop, recirculatory system. Fish reared in close, controlled environments require an even better degree of water quality compared to free range fish (Rogers et al., 2014). Poor quality can result in an aquaponics system collapsing due to poor fish mortality (Liang and Chien, 2013). Dissolved oxygen is amongst the critical water parameters that have to be maintained in the system in order to ensure optimum water quality (to be kept between the range of 4 to 8 mg/L), carbon dioxide, ammonia, nitrate, nitrite (to be kept between the range of 3-100 mg/L), pH, chlorine, and other characteristics ((Endut et al., 2010);(McGuire, 2015) The stocking density of fish, the growth rate of fish, feeding rate and volume, and related environmental fluctuations can prompt rapid changes in water quality. As such, constant and vigilant water quality monitoring is required to keep the system running smoothly (Fox et al., 2010).

Aquaponics does have its challenges as it is mostly an organic system. Aquaponics is not immune to pests but there are biological and natural means that can be implemented to reduce the effects of pests on the plant biomass in aquaponics without it being intoxicated (Variyar et al., 2016). Pests are one of the biggest challenges that aquaponics faces, especially for commercial farmers as this can destroy their entire produce and cause a complete loss resulting in systems failing and being shut down. Therefore, it is important to be watchful for pests. Most pests can be repelled using apple cider vinegar and bicarbonate of soda which are both natural and organic (Shafahi and Woolston, 2014). E coli is another bacteria that can negatively affect the fish component of the system. Fish farmers have to be constantly vigilant of e coli infections on fish as this can cause havoc in the system (Fox et al., 2012). Aquaponics is a complex and specialised practice, however, it is not impossible therefore, it is important for farmers to monitor and maintain the systems consistently in order for them to be a success.

Below is a pie chart of water usage in various sectors of the economy:

Figure 3: Pie Chart showing agricultural water usage



Source: https://sewageoceanpollution.weebly.com/statistics--graphs

Agriculture is the largest contributor to pollution and ultimately climate change. It is also one of the most water intensive industries (FAO, 2016). The carbon-intensive activities associated with agriculture are the main contributors to pollution, this is indicative of the need for transformation and cleaner technological advancements in the agricultural sector. The backbone of almost all the global economies is agriculture and if it is not transformed to be cleaner and sustainable, the long-term effects will compromise the future. Aquaponics on the other hand is a greener agricultural practice in the sense that it is less carbon-intensive and uses less water compared to traditional farming methods. Albeit greener, aquaponics is still a highly specialised form of farming that requires extensive knowledge on chemistry which is a disadvantage (Forchino et al., 2017).

The primary natural advantages of aquaponics result from its shut circle structure with the yields of aquaculture turning into the contributions for crop generation. Water protection is incredibly expanded contrasted with customary agribusiness. Likewise, with hydroponics, aquaponics produces proportionate harvest yields utilizing just 3-10% of the water system water utilized for modern agribusiness (Khan, 2006). Water is just lost through dissipation also, any essential water trades (Rakocy et al., 2006). This might be the most significant advantage of aquaponics as populace development and monetary improvement are enormously expanding water pressure. Farming is assessed to represent over 60% of worldwide water request and this will just build (Walraven, 2014). Also much of this water originates from non-replenishable springs, for example, the Ogallala spring in the Joined State's Midwest (Kim et al., 2013). The consumption of these springs will significantly diminish or kill horticulture in a considerable lot of the world's incredible harvest delivering areas. In request to manage these inescapable deficiencies innovations, for example, aquaponics and hydroponics must shoulder a more prominent segment of yield generation where proper. Aquaponics closed loop configuration additionally contains every one of the supplements inside the framework, anticipating any spillover or water impedance that has been a significant issue with traditional farming. The US Environmental Protection Agency (EPA) has evaluated that 70% of all stream and waterway sullying is from mechanical horticulture (Delaide et al., 2017). It additionally has the potential for lower supplement inputs (fish feed and supplements rather than manure), particularly if water trades are limited. Also the recycling framework empowers the cooperative connection between the fish also, microscopic organisms which gives nitrates to the plants. This relationship wipes out the requirement for artificially made manures which are commonly created through the vitality serious Haber-Bosch process (Fan and Brzeska, 2016). This decreases the exemplified vitality contribution for the framework, decreasing ozone harming substance emanations. This advantage can be additionally expanded by utilizing low vitality, privately sourced fish feed alternatives. At last, the recycling framework dispenses with the requirement for soil. This significantly expands the region we have accessible for nourishment creation and permits the execution of high return frameworks in high populace focuses. The benefits of carrying nourishment closer to individuals are examined in the accompanying area (Healey, 2015).

Two distinctive creation frameworks were considered in this examination. The UVI framework (College of the Virgin Islands) is an increasingly conventional way to deal with business aquaponic creation that underlines aquaculture and uses pontoon generation systems. It requires considerable gear venture and higher operational costs. Despite the fact that it can give high yields its business feasibility might be compelled by the accessibility of an appropriate market for the fish (Rakocy et al., 2006). The Bright Agrotech framework accentuates produce generation and uses a vertical, media filled, tower based framework. The Bright Agrotech framework requires lower venture and operational expenses and might be suitable for a more extensive scope of business sectors (Rakocy et al., 2016). Techniques for improving the business suitability of aquaponics are talked about alongside a correlation with the reasonability of absolutely hydroponic frameworks. It is presumed that aquaponics ought to be delegated a way of life business or social enterprise and moderate development of the business is normal for the time being future because of rivalry with hydroponics for a similar imprint sections (Jones Jr, 2016). As complex as aquaponics might be, provided it is consistently managed and maintained, the benefits outweigh the liabilities.

2.4.1. Advantages of aquaponics food production:

- Sustainable food production: Food produced in aquaponics is organic and sustainable as it uses minimal water and it is a recirculatory system, therefore the water is recycled.
- Two enterprises are combined (fish and plants) joined to a common nitrogen source: This increases potential for commercialisation and has the potential to expand to the point of employment creation and local economic development.
- Water efficient with less evaporation than in traditional farming: Aquaponics is a closed system and normally the system would be placed under some form of covering in order to reduce the evaporation rate.
- Completely soilless: Soil has the potential to bring toxicity to surrounding water bodies due to pesticides from agricultural activites.
- Organic: Aquaponics uses little to no fertilizers. When fertilisers are used, organic fertilisers are normally used as they have no artificial chemicals.
- Higher yields in minimal time frames
- Organic management of the system
- Biosecurity in a closed system with minimal risk of external contaminants
- Controlled production, which reduces risk and loss
- Flexible and can potentially thrive in non-ideal planting environments
- Waste is minimal in aquaponics
- Daily tasks of managing the system are minimal and not labour intensive as traditional farming methods therefore gender friendly.
- Financially feasible for both subsistent or commercial farmers as there are increased harvesting periods with minimal external risk on crops.

(Somerville et al., 2014)

2.4.2. Disadvantages of aquaponic food production:

- Aquaponics has a potentially expensive start-up; however, it is a long-term investment.
- It is a complex system therefore, it is imperative to have knowledge about all three components involved in aquaponics in order to ensure its success.
- It is a system that requires extensive calibration order to meet the nutrient requirements of both fish and plants.
- Requires optimal temperature conditions for both plants and fish which are not always possible.
- Limited management options compared to hydroponics (less employment opportunities)
- The slightest errors or imbalances to the system can result in the system collapsing or failing.
- Regular maintenance and monitoring is essential to the success of the system.
- A reliable source of energy is mandatory to the running of an aquaponic system.

- Aquaponics cannot solely provide a complete diet, supplementation from other food and nutrition sources required for a wholesome diet (Somerville et al., 2014).

Aquaponics is a complex agricultural system that requires the integration of fish and plants. In order for the system to function, there are basic components which are required. These components include; Fish tanks, hydroponic units, pump and a sump tank (may not be present in hobby scale systems) (Somerville et al., 2014). System components are essential to the functionality of aquaponics, without these components mentioned before, the system is bound to collapse. Therefore, it is essential to know which components are imperative for start-up aquaponics.

2.5. Horticulture Systems

Below is an illustration of three different types of grow mediums in aquaponics and all three have their own advantages and disadvantages:

Figure 4: Horticulture systems in aquaponics

Source: Media Grow Bed, NFT and DWC, From Left to Right (Goddek et al., 2015b)

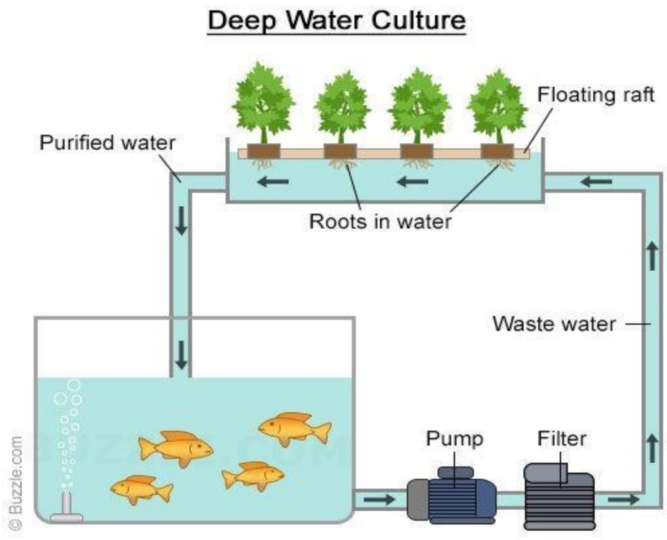
The three growing methods are the most commonly used in aquaponics. All three methods have their positives and negatives (Hart et al., 2013). Aquaponics is an emerging practice therefore it is imperative to maintain and monitor the system daily which is unattractive to most aspiring farmers.

Horticulture systems are determinants of whether the biomass output of the system will Aquaponics combines two of the most productive systems in their respective fields (Higgins, 2015).

The climate change challenges that the world is facing has led to the growing acceptance of recirculating aquaculture systems globally because of their benefits which include; higher yields, organic procedures in the system, less vulnerable to climate conditions and less demanding of vast land to grow food. (Hunter et al., 2017).

2.5.1. Deep Water Culture

Figure 5: Diagram of deep-water culture



Source: Rakocy (2012)

Deep water culture (DWC) or floating raft method consists in circulating the waste water through an external mechanical and biological filter and later through long canals with rafts floating on top. Plants live in pots within holes on the rafts and their roots hang down into the nutrient rich water, absorbing that nutrients and cleaning it.

This is the method preferred in large scale aquaponics, usually monoculture crops like leafy vegetables with high stocking fish density.

The biofilter before the canals can be removed if the stock density is low. In this case, the bacteria living in the canal walls and the bottom of the raft can be enough for decompose the NH_3 and the solid waste (Morais et al., 2016). Only a small mechanical filter should be used for the big solids. In the rest of cases, a special filtration unit should be implemented. It would usually consist in two stages, the mechanical and the biological. In the mechanical stage, a series of physical barriers each one with smaller holes than before are used for trapping all the solids (Rahman, 2016). The barriers should be periodically cleaned with clean water for removing the solids. The second stage consists in an aerated chamber filled with high surface materials for allowing a colony of nitrifying bacteria to live in. As opposite with media bed systems, this high surface materials do not have to sustain weigh roots so light cheap plastics can be used like nets or bottle caps (Rahman, 2016).

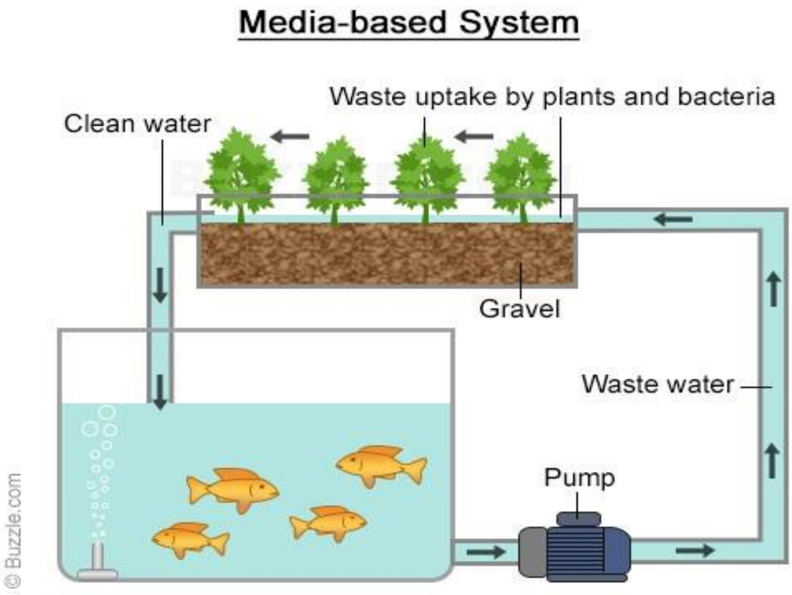
Canals are made of strong and inert materials with their interior layer appropriate for food production. The water inside them should have a retention time between one and four hours for allowing an adequate replenishment of nutrients. Higher water speeds allow more nutrients to come in contact with the roots, so narrower canals are preferred to “squarish” ones because they allow higher speeds without changing the retention time (the extreme situation of this can be found in the next method, NFT) (Rafiee and Saad, 2005). Finally, aeration is an important feature happening in the canals. Roots need to breathe and all the DO in the water will probably be consumed in the biofiltration process. Thus, an artificial aeration system is needed along the canal for provide enough DO in the water for the roots (Rakocy et al., 2006). A method for improving aeration (that doesn’t exclude the need of aeration) can be to let space between water and raft. This allows a portion of the plant roots to be in contact with oxygen, and the air to dissolve in the water.

Floating Rafts.

Floating raft frameworks are the customary generation strategy for enormous scale aquaponic and hydroponic tasks as a result of its high generation yields, basic plan, and low cost (Shafahi and Woolston, 2014). Plants are developed in polystyrene sheets (pontoons) which buoy over the supplement arrangement. Plant roots hang down straightforwardly into the water. Pontoon frameworks are the most water serious hydroponic unit in light of the huge volume of standing water. In pontoon frameworks 75% of the water can be situated in the hydroponic units while in other frameworks most of water is situated in the fish tanks (Trang and Brix, 2014).

2.5.2. Gravel Beds

Figure 6: Diagram of Media-based system



Source: (Rakocy, 2012)

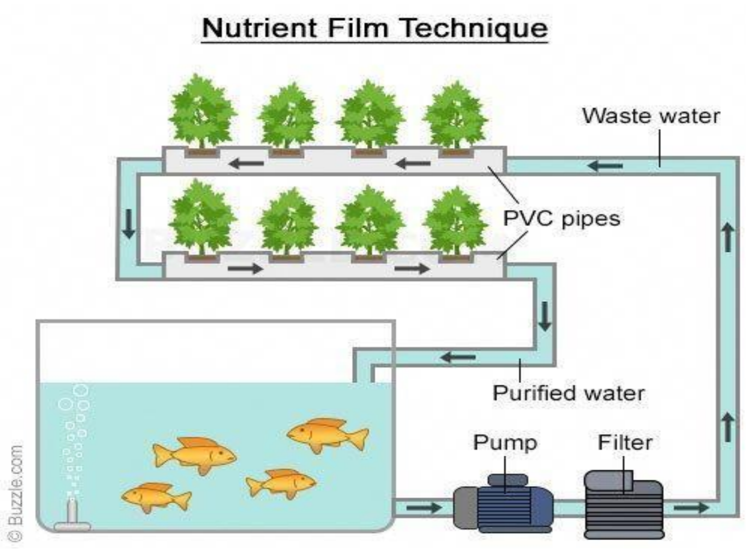
Media filled bed is an aquaponic system that consist in a grow bed filled with an inert media as clay, gravel or sand where the roots are. The water is circulated from the fish tank to the bed where live both bacteria and plants and then returned to the fish tanks once is clean. The medium in the media-filled beds is support to the plants as it supports the stems to not bend when the plant begins to fruit. It also supports the bacterial component (mineralization) and biological (bacterial biofiltration) (Reyes Lastiri et al., 2018). The material that compose the medium has to accomplish a list of characteristics: it has to have a large surface area while remaining highly porous for the purpose of air and water, has to be inert and pH neutral, not dusty and non-toxic. The most commonly used media for aquaponics is volcanic
gravel, expanded clay, river gravel and sand.

Water can be delivered to the bed in different ways depending on the degree of technology desired. The easiest way is simply distributing uniformly thorough the medium using pipes with holes and is a perfectly acceptable design (Reyes Lastiri et al., 2016). The preferred method for ensuring a good
ratio of air and water into the system is the flood-and-drain method.It consists in plumbing water until the media bed is flooded and then don’t plumb it again until the level of water has drained until certain high. This allows the existence of three areas or micro-ecosystems in the beds, the dry zone, the wet zone and the flooded zone.

Each area hosts a different group of organisms that participate in the process of water cleaning depending on their preferences of humidity and air. The most important section, the wet zone retains always the humidity necessary for roots and bacteria to live but ensures an air flow once per cycle when the water gets drain, allowing roots and organisms to breathe (Ru et al., 2017). From this organism the most important are the nitrifying bacteria that process NH_3 into nitrates, but other notable mentions can be fungus and earthworms that contribute in the degradation of the solid wastes.

2.5.3. Nutrient Film Technique

Figure 7: Diagram showing Nutrient Film Technique (NFT)



Source: Rakocy (2012)

In Nutrient Film Technique (NFT) water from aquaponics is circulated in a thin layer through almost horizontal pipes. Plants grow in openings that have been made in the piping, with the roots placed in a position whereby they are touching the water which is passing through.

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The rest of the plant grow up and around the exterior of the pipe.

It always needs an external filtration unit that can be formed by the same components as the filter in DWC described previously.

The method operates as the water is pumped into the tubes continually forming only after passing through the filter, a shallow stream rich in nutrients running in the pipe's bottom.

The remainder of the pipe is empty with air that allows roots to breathe, so artificial aeration systems are not essential. Because they have sufficient air, roots can resist a non-stop stream that allows for quicker nutrient consumption and plant growth (Kyaw and Ng, 2017). Water flow in the root systems should not exceed 1-2 liters / minute to allow sufficient oxygen.

There are particular tubes for NFT when it comes to tubes. Usually this pipe has a square shape to allow the maximum quantity of water to pass through the pipe without it. An important factor to be taken into account is the type of root system of the plants; plants with dense root systems like tomatoes or mint can clog easily the pipe stopping the water stream. Finally, the length of these pipes should never exceed 12m in order to assure that even the last plant on the row receives enough nutrients (Kyaw and Ng, 2017).

Sump Tanks.

Sumps are used to recollect all the solution water after it has passed through the hydroponic units (or fish tank if reversed) and then pump it from a single point back to the top of the system. Sumps are typically where supplemental chemicals are introduced to allow for mixing and dilution outside of either growing or fish raising areas (Trang and Brix, 2014). Systems should only rely on one pump regardless of size to reduce failure points and prevent an overflow of water in either the fish tanks or hydroponic units which could result in crop losses(Somerville et al., 2014). The importance of this is stressed by aquaponics researcher James Rakocy in his quote “One God, One Country, One Pump”.Aquaponic systems may require additional components in addition to those described.

Nitrification is the chemical process that drives aquaponic systems. In nitrification ammonia (NH_3) is converted into nitrite (NO_2^-) by the bacteria in the genus *Nitrosomonas* which is then converted to nitrate (NO_3^-) by *Nitrobacter* bacteria (Trang and Brix, 2014). While ammonia is highly toxic to fish and not readily available for plant absorption, nitrates are an optimal nitrogen source for plants and are not toxic to fish except in high concentrations.

Plant Nutrients:

Maintaining adequate nitrification levels is achieved through proper system design and operation. Within the nitrification process is a second important nitrogen balance. Ammonia in solution is constantly moving towards equilibrium with ammonium (NH4+), which is significantly less toxic than ammonia (Þórarinsdóttir et al., 2015). Ammonia dominates the equilibrium at high pH ranges and ammonium dominates at low pH ranges with an even mixing point around pH 8 (Walraven, 2014) This system is in conflict with nitrification in aquaponics as nitrification is most efficient at high pH. Striking a balance between nitrification and a beneficial ammonia : ammonium ratio is important to running a productive system.

Biological Surface Area (BSA) is a key factor that influences nitrification and determines how productive a system can be (Walraven, 2014). BSA is a measure of the available surface area in a system that that nitrifying bacteria can grow on. Total system BSA is measured in ft2 and the specific BSA of different media is measured in ft2/ft3. Surface area is directly proportional to a system's nitrification rate and a low BSA will lead to fish toxicity and plant nutrient deficiency (Walraven, 2014).

There are no negative consequences with excessive BSA. Raft systems are more likely than media-based systems to be deficient in BSA due to the high surface area associated with media and an additional biofilter may be required for raft systems to ensure proper nitrification (Yep and Zheng, 2019). Proper sizing of BSA is critical in the design of any system. The minimum recommended amount of BSA in a system is 2.5 ft2/gal, although 5-10 ft2/gal is beneficial especially in establishing systems (Storey, "Biological Surface Area in Aquaponics," 2013). Included are the specific BSA and void ratio for common aquaponic media options.

2.4.4. Low-Cost

A low-cost aquaponics system is low-tech using low-cost locally available materials. The aquaponics system is closed-loop with a maximum of 30m2 for the growing area (Somerville et al., 2014). The rearing of fish and plants in a small-scale, low-cost aquaponics system allows them to meet their daily subsistence food and nutrition security set by the sustainable development goals 2030. The definition is derived from the FAO Small-scale aquaponics food production technical paper (2014)

2.6. Nutrient Flow

Plants need macronutrients (e.g., C, H, O, N, P, K, Ca, S and Mg) and micronutrients (e.g., Fe, Cl, Mn, B, Zn, Cu and Mo), which are basic for their development. Hydroponic arrangements contain well-characterized extents of these components and are added to the hydroponic arrangement in ionic structure with the special case of C, H, and O, which are accessible from air and water (Wongkiew et al., 2017). In aquaponics frameworks, plant supplement contribution from the fish tanks contains broke down supplement rich fish squander (gill discharge, pee and excrement), including both solvent and strong natural aggravates that are solubilized to ionic structure in the water what's more, acclimatized by the plants. To support sufficient plant development the convergences of smaller scale and macronutrients should be observed. Occasionally a few supplements may should be added to change their fixation, for instance iron is regularly inadequate in fish squander (Shetty, 2015). Aquaponic frameworks should have the option to have diverse microorganism networks that are engaged with fish waste handling and solubilization. Alkali ($NH4+$) from fish pee and gill discharge can develop to lethal levels if not expelled from the framework. This should be possible by step-wise microbial change to nitrate (Ru et al., 2017).

One of the most significant microbial parts is the nitrifying autotrophic microscopic organism’s consortium that is set up as a biofilm on strong surfaces inside the framework and is chiefly made out of nitroso-microorganisms (e.g., Nitrosomonas sp.) and nitro-microscopic organisms (e.g., Nitrospira sp., Nitrobacter sp.) (Roosta and Hamidpour, 2011). The alkali inside the framework is changed over into nitrite ($NO2-$) by nitroso-microorganisms, before being changed into nitrate ($NO3-$) by the nitro-microscopic organisms. The last result of this bacterial change, nitrate, is impressively less dangerous for fish and because of its bioconversion, is the principle nitrogen hotspot for plant development in aquaponics frameworks. In many frameworks, an uncommon biofiltration unit where escalated nitrification happens is required (Rafiee and Saad, 2005). The ideal proportion among fish and plants should be distinguished to get the correct harmony between fish supplement generation and plant take-up in every framework. Rakocy, reports this could be founded on the sustaining rate proportion, which is the measure of feed every day per square meter of plant assortments (2016). On this premise, an incentive somewhere in the range of 60 and 100 g $day-1$ $m-2$ has been prescribed for verdant greens developing on pontoon hydroponic frameworks. (Forchino et al., 2017) found an ideal proportion of 15–42 grams of fish feed $day-1$ $m-2$ of plant developing with one African catfish (Clarias gariepinus) for eight water spinach plants (Ipomoea aquatica). Consequently, finding the correct parity requires central learning and encounters with respect to the accompanying criteria:

- kinds of fish and their nourishment use rate

- organization of the fish nourishment, for instance, the amount of unadulterated proteins changed over to Total Ammonia Nitrogen (TAN)
- Regular nourishing
- hydroponic framework type and plan
- types and physiological stages of developed plants (verdant greens versus fruity vegetables)
- plant planting thickness
- Mixture of the water affected by the mineralization pace of fish squander. Furthermore, since fish, microorganisms and plants are in a similar water circle, natural parameters, for example, temperature, pH and mineral focuses should be set at a trade-off point as close as conceivable to their individual ideal development conditions (Þórarinsdóttir et al., 2015).

2.7. Nutrient Balance

Nitrification and mineralization produce sufficient amounts of the essential nutrients necessary for healthy plant growth including nitrogen, phosphorous, copper, and zinc among others. However, deficiencies can still occur, and nutrient supplementation is often required in aquaponic systems (Davis, 2015).

Iron is a common nutrient that needs to be supplemented in any aquaponic system.

Iron can be present in two forms ferrous iron (Fe^{2+}) which is soluble and ferric iron (Fe^{3+}) which will precipitate out of the solution. For plant absorption iron needs to be in its ferrous form and chelating agents are used to ensure the iron is bioavailable (Delgadillo-Díaz et al., 2019).

Fish toxicity can be an issue with chelating agents and for this reason FeEDTA is not recommended, FeDTPA and FeEDDHA are preferred sources(Love et al., 2015b). The UVI system recommends using 2mg/L (7.58 mg/gal) of iron dosed every 3 weeks, however this can also be broken up in weekly doses.

Potassium, Calcium, and Magnesium can also exhibit deficiencies in aquaponic systems. While any of these nutrients can be deficient separately, they often have overlapping interactions because all three are present as positive ions in the system (K^+, Ca^{2+}, Mg^{2+}) (Delgadillo-Díaz et al., 2019). Plants can have difficulty recognizing and absorbing the proper ion balances even if sufficient levels off all nutrients are present because the nutrients can outcompete each other. Potassium is the most likely to be deficient, calcium deficiencies are also very common and is magnesium a less common issue.

When managing these nutrients it is necessary monitor both their overall concentrations as well as their relative ratios.

2.8. Microbes in aquaponics

The five most significant factors for good nitrification are: high surface zone media for microorganisms to develop and colonize; pH (6–7); water temperature (17–34°C); DO (4–8mg/liter); spread from direct introduction to daylight (Tyson et al., 2004). System cycling is the underlying procedure of building a nitrifying microscopic organisms state in a new aquaponic unit. This 3–multi week procedure includes including a smelling salts source into the framework (fish feed, alkali based manure, up to a focus in water of 1-2 mg/liter) so as to animate nitrifying microorganisms development (Kim et al., 2013). This ought to be done gradually and reliably. Smelling salts, nitrite and nitrate are observed to decide the status of the biofilter: the pinnacle and consequent drop of smelling salts is trailed by a comparative example of nitrite before nitrate begins to amass. Fish also, plants are possibly included when alkali and nitrite levels are low and the nitrate level starts to rise. Ammonia and nitrite tests are utilized to screen the capacity of the nitrifying microscopic organisms and the presentation of the biofilter. In a working framework, alkali also, nitrite ought to be near 0mg/liter. Significant levels of either alkali or nitrite require a water change and close monitoring (Buzby and Lin, 2014) . Generally, poor nitrification is expected to an adjustment in water temperature, DO or pH levels.

Another class of micro-organisms normally happening in aquaponics is that of heterotrophic microscopic organisms. They break down the strong fish squander, discharging a portion of the supplements into the water in a procedure called mineralization.

2.9. Water quality in aquaponics

Water is the driving force of aquaponics, without it there can be no aquaponics. Water is the medium by which fish receive their oxygen and plants receive their nutrients. Therefore, it is imperative for aquaponics farmers to have basic knowledge on water chemistry in order to manage the system efficiently. Aquaponics requires the monitoring and management of five key parameters, they include: dissolved oxygen (DO), pH, water temperature, total nitrogen concentrations (KH) (Carruthers, 2015). It is crucial to know the required parameters for both fish and plant components in order to ensure that the aquaponics system thrives. However, should there be a nutrient deficiency in the system, it is possible to buffer the system with nutrients in order to supplement the deficient nutrients (Zou et al., 2016).

The recommended ranges for each water parameter are as follows;

- pH: 6–7
- water temperature: 18–30°C
- Dissolved Oxygen: 5–8mg/litre
- Ammonia: 0mg/litre
- Nitrite: 0mg/litre
- Nitrate: 5–150mg/litre
- KH: 60–140mg/litre

pH has proved to be the biggest threat to water quality in aquaponics. Often, acids are used to buffer the pH, however, it is always best to harvest rainwater in order to reduce pH challenges when practicing aquaponics. (Kyaw and Ng, 2017). Calcium carbonate which is found in sea shells and egg shells is a good, natural pH buffer that balances it organically. It is imperative to do regular water tests for all five parameters in aquaponics in order to ensure the success of the system. Neglecting regular water quality monitoring can result in fish mortality and the ultimate collapse of the system.

2.10. Biomass Output

The success of an aquaponic system is determined highly by the biomass produced as the final output in the system. Biomass can be defined as the output or product of a complex process. Aquaponics combines two vital farming enterprises, hydroponics and aquaculture (Endut et al., 2010). However, there is a third bacterial component to aquaponics which determines the biomass output. If the bacterial component is neglected, it shows in both the fish and plant biomass as it either dies or is of poor, inedible quality. The bacterial component drives nitrification. Nitrification is the process of the bacteria converting fish waste from the aquaculture component into nutrients which are ready and suitable for uptake in the hydroponic component. The process of nitrification includes the breaking down of ammonia (which is toxic to fish) by *Nitrosomas sp.* bacteria into nitrite(Wongkiew et al., 2017). Nitrite is further broken down into nitrate by *Nitrobacter sp*. Bacteria. into nitrate. Nitrate is less toxic to fish biomass and presents itself as a form of nitrogen which is useful to the plant biomass in an aquaponic system. The bacterial component is crucial for the success and yield of biomass output in an aquaponic system. Without it, there would be no nitrification and sufficient breaking down of nutrients which would inevitably result in the collapse of the system.

2.11. Grading

A practice that can help to increase the productivity of the systems is grading the fish at certain stages. Grading is a process where the fish are sorted according to size, and the smaller fish are removed. These fish are removed because they are not converting feed into biomass efficiently (Mirzoyan et al., 2010). Fish that grow slower than the ideal growth rate are known as genetic runts. These fish do not have the potential to grow at an efficient rate, and should be identified and removed from the system as early in the production cycle as possible (Mirzoyan et al., 2010). Grading can be performed by drawing a mesh grid with holes of a specific size though the water body. At the stage when grading is performed, the majority of the fish should be of such a size that they cannot fit though the mesh screen. The genetic runts are smaller and fit though the screen, after which they should be removed from the system and culled and discarded of humanely (Mirzoyan et al., 2010). The case study farms do not grade their fish. This decreases productivity and increases the number of smaller, un-marketable fish harvested.

2.12. Financial Viability

Financial viability is imperative in the planning and execution of any project. Any project often requires funds for establishment and maintenance, these funds are often allocated according to fixed costs, operational costs and direct costs. There is no one specific way to determine financial viability. There are numerous methods and techniques such as cost-benefit, feasibility analysis and many other techniques that are useful in determining the financial viability of a project. In 1997, Bailey, Rakocy, Cole and Schultz performed an economic analysis of an early version of the UVI commercial aquaponics system. Each system consisted of 4 fish rearing tanks and 2 hydroponic tanks. For the analysis, pro forma enterprise budgets were used to itemize individual costs in order to examine their impact on total production cost. A break-even analysis was conducted in order to determine appropriate sales volume and price for each product to recover costs. A cash flow budget was developed with net present value and internal rate of return also being calculated. In addition to examining the costs associated with the aquaponics system itself, the analysis also took into account the costs of additional infrastructure components that may be required for production(Sunny et al., 2019). These consisted of water collection tanks, feed and cold storage facilities, office and work room areas, trucks, tractors and wagons, greenhouse nurseries, brood fish holding and breeding tanks, and a fish hatchery. There are numerous completely working business and little scale aquaponic units around the world. Aquaponic frameworks can be created not just in tropical and subtropical districts, where great climatic conditions permit all year generation, yet additionally in cooler regions of the existence where winter seasons last as long as a half year. The topic of running an aquaponic framework in a particular place requires a complete money saving advantage examination that should survey its conceivable accomplishment upon certain monetary, ecological, calculated/administrative and social conditions (Short et al., 2017). Numerous variables must be considered before setting out on an aquaponic venture, regardless of whether it is for household creation or all the more financially engaged. Many star-up aquaponic systems have failed. A choice to make a business venture requires huge investigate, a field-tested strategy and a hazard examination. The capital cost for each system in 1997 was approximately $22,642 with fish and lettuce components costing $13,780 and $8,863, respectively. Farms with 6, 12, or 24 individual systems are expected to have capital costs of $135,852, $271,704 or $543,408, respectively with additional capital expenses of $149,282, $268,564, or $487,128 for the additional infrastructure components listed in the previous paragraph(Shafahi and Woolston, 2014).

Three organisms are involved in the optimum performance of aquaponic systems. The plants and fish are the cash crops, while nitrifying bacteria play an important biofiltration role, converting toxic fish waste ammonia (Tyson and Simonne, 2014) to nitrate nitrogen, one of the most important mineral nutrients required by plants. The choices of fish and aquatic organisms have an economic, environmental, and legal component. For example, tilapia is one of the most common aquaculture fish due to its tolerance of a wide range of water quality conditions(Webster and Lim, 2006), its favorable feed conversion ratio (1.5–3 pounds of feed/pound of fish (Chapman et al., 2012) and its fast growth under warm conditions (market size in 6–12 months). It fits well when grown with warm-season vegetable crops like tomatoes, peppers, or cucumbers. Tilapia has high-quality, textured white fillets which present well at restaurants. Worldwide tilapia farming is expanding at a rate of 12% to 15% annually. However, tilapia is sensitive to low temperatures and stop feeding at 60°F, with lethal temperatures beginning at 50°F and below. Also, inexpensive foreign imports depress wholesale prices, resulting in the need for farmers to seek marketing outlets that cater to the local production of food or live fish markets where higher prices could be expected (Petrea et al., 2016). Other fish suitable to aquaponics but requiring more stringent water-quality conditions are channel catfish, koi, and other ornamental and bait fish(Love et al., 2014). Malaysian prawn and red claw crayfish also have been used in aquaponic systems, but because they are non-native species their use in Florida is restricted (Tyson and Simonne, 2014)

2.12.1. Economic factors

One of the principle factors that decide the conceivable accomplishment of aquaponics is its ability to work in unconventional agricultural environments. The mix of both fish and plants pairs the dangers of the speculation that, so as to be gainful, must augment both plant and fish creation and incomes. This suggests an investigation on the potential markets is a fundamental advance towards the advancement of a marketable strategy, as it ought to reasonably discover all the potential items, distinguish the net revenues and recognize the key clients (Variyar et al., 2016). A typical mix-up is to inquire: "What would I be able to create?" rather than the more significant inquiries: "What would I be able to sell?", "To whom am I going to sell?", and at exactly that point "How am I going to create it?" Market examination ought to recognize the most beneficial items and the most cost-effective the executives. This infers the particular decision of fish can be fundamentally unique in relation to the species by and large utilized in aquaponics, principally attributable to advertise request and the expenses of creation (Yep and Zheng, 2019). In the basic leadership process, there are significant contrasts between a system suitable for self-utilization and a market-situated one. While the previous can for the most part depend on retail costs to appraise the overall revenues, the business scale adventures have to discover markets that may be nearer to discount costs, particularly on account of largescale tasks. Nonetheless, little scale frameworks can't profit by economies of scale (e.g. a little nursery has a greater expense for every square meter than does a bigger one), which implies non-business farmers may confront higher creation costs (Ottinger et al., 2016).

While aquaponics may, somewhat, be recognized as a "natural" generation choice in North America, this isn't similarly valid in Europe where "natural" still applies just to soil-based creation (Nozzi et al., 2018). The uplifting standpoint got from an all the more naturally sound creation can support higher incomes in Western markets; be that as it may, this may not be similarly conceivable in creating nations where clients' decisions are still essentially cost arranged. On the advertising side, a preferred position could emerge out of impression naming, as aquaponics gives off an impression of being the best aquaculture framework in wording of water preservation and a contamination free arrangement that can bolster farming with predictable investment funds in manures and compound inputs. Notwithstanding, appropriate item improvement on this premise still should be done, giving additionally that aquaponics moves towards more vitality impartial administration techniques. One of the limits that still averts aquaponics from completely extending around the world is that its speculation costs are practically twofold those of standard hydroponic cultivating (Alshammary, 2016). In any case, this conviction is halfway gotten from the mixed up thought that aquaponics is an insignificant plant creation framework rather a recycling aquaculture framework (RAS) that also bolsters horticulture (Asia, 2006). Whenever looked at against a standard RAS, aquaponics shows reliable preferences as far as capital and working expenses and for the degree of effortlessness of the framework. More prominent achievement could be accomplished whenever cost-sparing plans/ ventures had the option to bring aquaponic arrangements closer to the expected outcomes of hydroponics. In any case, this would require more exertion to concentrate on creating easier frameworks. The likelihood to set up aquaponics in ominous atmospheres relies upon the degree of speculations required for building nurseries and running propelled atmosphere control frameworks to keep up ideal water and air temperatures, stickiness and ventilation (Ridler and Hishamunda, 2001). This would expand the underlying and running expenses, however in any event, on this level, the venture costs for the nursery offices may not contrast essentially from those for hydroponics.

2.12.2. Low-Cost

A low-cost aquaponics system is low-tech using low-cost locally available materials. The aquaponics system is closed-loop with a maximum of 30m2 for the growing area. The production of fish and plants within a small area allows small scale farmers to achieve the daily income target of USD1.25 and food and nutrition security set by the sustainable development goals 2030 (Fischer and Bianchi, 1984)A low-cost aquaponics system is a system that could address the current challenge to source expensive materials to start-up an aquaponic system.

Factors affecting financial viability:

- Cultural Perception
- pH variable
- Temperature variables

- Feed Conversion ratio

2.13. Local Economic Development

The development of the economy on a macro and micro scale is vital and key to achieving local economic development. Local economic development as defined by (Nel and Rogerson, 2005)is “A process in which local governments and or community-based groups manage their existing resources and enter into partnership arrangements with the private sector, or with each other to create new jobs and stimulate economic activity in an economic area”. Partnership is key in local economic development because, without the collaboration of government and

Local economic development is potentially a tool to respond to the current climate change crisis. Climate change is the extreme shift in weather patterns due to an increase in carbon intensive human activities. The increase in carbon intensive activities is due to human activities that support economic development, therefore if local economic development policies are informed by the current issue of climate change the world is facing, local economic development will be successful. Aquaponics is one of the unconventional farming methods that respond to climate change as it proves to be a climate change adaptation strategy (Bennett and Payne, 2019). Aquaponics, although an emerging practice addresses numerous global issues such as; food security, poverty alleviation, climate change, job creation and overall local economic development. Aquaponics has the potential to be a pathway in which local economic development can be achieved. For example, aquaponics has commercial potential whereby employment opportunities can be created within the agricultural sector and social entrepreneurship can be encouraged because of the potential for commercialisation that aquaponics has (Goddek et al., 2015b).

Below is a diagram indicating the strengths and benefits of local economic development.

Figure 8: Diagram showing benefits of LED

Source: http://cariled.org/about-led/definitions//

The diagram above indicates the importance of local economic development as a social collaboration stimulant. Activities that are geared towards local economic development in communities have a high potential of igniting social cohesion and getting locals to find opportunities of solving local problems, whether economic, environmental or political, with other locals (Rogerson, 2010). Aquaponics is a good example of a potential local economic development initiative that can stimulate local communities to pursue social entrepreneurship, create employment opportunities and ultimately contribute to local economic development.

From a theoretical stance, there is clear resonance with Harvey's (1989) concept of 'urban entrepreneurialism 'and of the role localities play as both sites and agents of economic development. The emergence of 'new regionalism' as a theoretical construct, and more recently 'new localities' thinking, represents a parallel reconsideration of the role of place within the development process (Rogerson, 2009). Compared to earlier articulations of 'localities' theory, new approaches recognise the multifaceted and multidimensional nature of the development process and the role localities play within this context, not least the need to articulate local processes within an increasingly complex globalized context (Bocken et al., 2014). For nearly 20 years South African localities, with the support of the state, have actively pursued LED in an effort both to achieve post-apartheid socioeconomic redress and to promote economic development. The extent of the country’s engagement with LED and associated policy development and support has attracted international attention(Nel and Rogerson, 2016). Before 1994, LED planning in South Africa was limited in scope, mainly confined to isolated local development interventions pioneered by municipal authorities in the largest cities.The private sector is imperative in ensuring successful local economic development.

Sustainability aspects of aquaponics in developing countries

Aquaponics can be used to improve the livelihoods of households and communities. Fish is an important source of protein in low- and medium income countries and vegetables improve nutrition (Tacon and Metian, 2013). Aquaponics could help to increase food security (Ericksen, 2008) and the food sovereignty. However, the costs of modern aquaponic systems might exclude the poor from its potential benefits: The dependency on electricity and water might limit its use in unplanned urban sprawl und rural areas where nutrition deficits in terms of food variety and protein are most predominant (König et al., 2016)However, under favourable climatic conditions (tropics and subtropics), aquaponic systems may be very simple, consisting of un-insulated outdoor units (low-tech). (de la Caba et al., 2019)state that very few inputs are needed for a basic unit (e.g. fingerlings and seeds). Yet these inputs are often locally limiting factors to food security. Depending on the specific conditions, aquaponics can provide a sustainable food source in low- and medium-income countries, especially where climate conditions are favourable

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Sustainability aspects of aquaponics at industrial food production scale

As a rule of thumb, many aquaponic professionals agree that a production unit becomes profitable when the area dedicated to vegetable growth exceeds 1000 m2 (Edwards, 2015). For large scale aquaponics (>1000 m2), fish and vegetable produce compete with standard products from horticulture and aquaculture. There are currently no recognized certification systems or legislation to recognize the positive environmental externalities of aquaponics(Villarroel et al., 2016). However, some brands are either striving to develop their own labels (for example Sweet Water Aquapons) or to obtain Global G.A.P. Certification. Energy for the system (pumps, aeration) can be supplied by the grid, with a built-in generator unit based on natural gas, or using photovoltaic energy. The dependence on external energy necessitates backup generators (using fossil fuel or biofuel) or batteries storing direct current for conversion to AC (Love et al., 2015b). Using renewable energy with photovoltaics improves energy efficiency, but also requires emergency equipment, thereby increasing costs (Kloas et al., 2015). Alternative energy systems and management strategies for large-scale horticultural production are in the development phase Water efficiency can be increased by incorporating rainwater or treated greywater, which is possible in temperate climate zones (Kloas et al., 2015) or by water reclaiming in arid areas.

From a life cycle perspective, there has been little discussion about the sustainability of materials used in aquaponics. One material that could be replaced yet successfully is the non-reusable rock wool (used as standard growing medium in hydroponics), or other recyclable materials used for growing beds. Adoption of these materials has to be balanced with economic viability and feasibility. New zero-discharge or highly efficient systems require improved management skills and may pose a greater economic risk. Efforts should be made to identify economically feasible aquaponics based on energy, water and climate management regimes (Suhl et al., 2016).

In practice, aquaponics balances environmental benefits with economic risk by appropriate technical and business model designs. The risk of economic failure due to system failure has already been analysed to some extent for recirculation aquaculture systems (RAS), indicating the need for a skilled and intensive risk management for “total” system control (Rawlinson and Forster, 2001).

Environmental Benefits of aquaponics as suggested by (Bosma et al., 2017)

- Reduces strain on depleted fisheries
- Reduces agricultural runoff & fish kills
- Avoids problems caused by open ocean fish-farms
- Requires a fraction of the water required by regular
- agriculture and pond culture
- Local production reduces transportation externalities

FOOD SECURITY AND FOOD ACCESS BENEFITS

- Provides fresh, local food in areas of:
- Low water conditions
- Limited arable land
- Polluted land
- Poor soil quality

- Overfishing/fishery collapse
- Poor road access

COMMUNITY DEVELOPMENT BENEFITS

- Hands-on teaching tool
- Incorporates into school curricula
- Teaches ecological literacy
- Serves as community locus
- Creates activity in the neighbourhood
- Provides job skills training opportunities

Urban Application

Bringing agriculture into urban settings is tantalizing for its food security and sustainability benefits. Aquaponics has the potential to do very well in urban environments because of its space efficiency and ability to grow produce without soil. Aquaponics can provide a means to bring healthy vegetable and protein sources into urban spaces usually devoid of these options. There are three main ways aquaponics can be implemented in urban areas: commercial systems, non-profit and community Systems and hobby scale Systems (Kloas et al., 2015)

Commercial Systems

Commercial aquaponic production in urban areas has the potential to produce large quantities of food in urban areas and is particularly attractive because it is a financially sustainable model. Commercial aquaponics has the ability to repurpose underutilized or unused space in cities such as rooftops and abandoned warehouses. Unfortunately to this point there has been a very high failure rate for commercial aquaponics both inside and out of urban area, calling its viability into question (Kanter et al., 2015). Several distributions strategies and common reasons for failures are listed below:

Distribution Models

CSA.

In a CSA (community supported agriculture) customers pay an upfront cost to receive a predetermined share of the farm’s yield every week. Memberships length can vary anywhere from three months to a full year. The CSA is advantageous to farmers for several different reasons. Most importantly it guarantees income from a particular customer for several months, helping to stabilize weekly income and reduce the need for farm to market itself once the CSA reaches a desirable level (Sunny et al., 2019). The sales for this period are received upfront which helps to free the business's cash flow. Another benefit is the sense of comradery created between the growers and the consumers. Members of a CSA often feel that they are a part of the growing process, sharing in both the risks and rewards of the farm. This relationship often gives members a sense of loyalty to the farm. Operating a CSA can help increase flexibility in an aquaponic grower's business model and assure adequate profit margins, especially in the early stages of development.

Farmers Markets.

Farmers markets have increased rapidly with the growth of the local food movement. In general, this bodes well for aquaponics as it gives growers another means to directly market their target consumers in a location where their local and sustainable qualities will be well received. However, the large growth of farmers markets has created a disparity and some markets are highly successful while others do not draw significant crowds due to location and other factors. Aquaponic growers should be careful to place themselves in markets where they will have the opportunity to meet their sales quota (Keller and MacNear, 2012). Additionally, growers should look to place themselves in exclusively food markets if possible because customers are focused specifically, on their food needs. Membership in a farmers' market will require interviewing with a market manager and detailed operational plans may be necessary (Keller and MacNear, 2012). Typical membership fees include an annual charge for floor space and a small percentage of all sales.

Grocery Stores & Food Retail.

Marketing to supermarkets in high population areas and large store chains are difficult as these operations have large distribution networks involving wholesalers and highly competitive contracts. Conventional supermarkets are cost focused and as such rely on a large distributor or several that can provide all the products for a store(Gonzales-Barron and Butler, 2011). In some cases where a single distributor is not used over 200 suppliers may distribute to one store (Barron and Dasli, 2010). These distributors are often responsible for

both the selection and delivery of products. Even organic focused stores which are quality focused and rely on their own set of distributors meet their stocking needs. In this noise it will be difficult for aquaponics to establish contracts with the majority of food retailers and distributors as cost competitiveness will likely reduce the profit margins to an unsustainable point except for very large-scale operations. Additionally, distributors and wholesalers may be wary of working with aquaponic growers due to concerns over consistent system production and commercial viability (Fan and Brzeska, 2016). Aquaponics may be able to
score contracts with local focused stores however the success and limits of this approach are entirely dependent on the store and local market conditions.

Restaurants & Food Service.

As with grocery stores restaurants rely on suppliers and distributors for the vast majority of their needs. These suppliers are common to almost all restaurants in a given location depending on weather they are quality focused or cost focused (Rockström et al., 2010) Local sources are only a concern in local focused restaurants. Aquaponics will have difficulty penetrating this market for the same reasons as retail markets; however there are possibilities for partnerships with local focused restaurants.

Reasons for Failure

Not Designed for Profitability.

Several commercial aquaponics operations have failed because they are based off inherently unprofitable systems. There are several well-known community-based aquaponic systems which operate as a non-profit entity.
These operations hold trainings as a way to fulfil their mission and generate additional income (Walraven, 2014). Several entrepreneurs have based their commercial systems off of the community systems presented at these trainings which has repeatedly resulted in failure (Bach et al., 2013) In this case entrepreneurs equate biological viability with commercial viability (Walraven, 2014)While the biological viability of aquaponics has been well documented commercial and subsistent viability has been far more elusive. These failures gain significant attention in the aquaponic community so the number of aquaponic producers attempting to commercialize this system should decrease dramatically.

Inappropriate Scaling.

Entrepreneurs often start their systems too large or scale them too quickly to reach advantageous economies of scale. While scaling is important starting with a large system greatly increases the likelihood of a crash. Young systems can take a year or longer to fully establish and diversify its bacterial populations system ecology (Storey, 2012). As such systems in early phases are more fragile and more likely to crash than older systems (Storey, 2012). Running a large system or scaling on quickly adds additional strain during this period. Adding high production quotas places additional strain on the business and making a mistake is very expensive at a large scale (Faul, 2014). To compound this, several entrepreneurs have attempted commercial aquaponics after switching careers and only possessing experience with personal, small scale aquaponic systems.

Underestimation of Expenses.

Entrepreneurs often underestimate labour expenses associated with commercial systems, especially during the establishment phase. In addition to planting and harvesting systems must be monitored and adjusted to maintain proper nutrient balances. Additional new systems are prone to leaks and clogging as operators become accustomed to the system and address flaws from construction(Suhl et al., 2016). Growers who do not utilize an owner operated model in which they participate in running the system will face greatly increased costs. When budgeting it is possible that entrepreneurs assess labor based on experience small scale systems or use estimates from established systems. Growers may also come into the industry with expectations of spending the majority of their resources to marketing (Love et al., 2014). Dr. Nate Storey from Bright Agrotech suggests that 90% of his time is spent selling and 10% is spent growing (2012). Energy and lighting requirements for greenhouses in northern latitudes also contribute significant expenses as seen with the Vertigrow investigation

Inadequate Pest Control.

Much of the literature surrounding aquaponics discourages the use of chemical pest control strategies for the danger it poses to fish (Rakocy et al., 2006)

High Capital Costs.

Aquaponics is highly capital intensive which requires growers to seek out investors and sources of debt (König et al., 2016, Goodman, 2011)Not achieving expected yields due to a previously mentioned mistake or other factor will cut into a grower's profitability and may impair their ability to pay back their debt, forcing the business to go under.

Community & Nonprofit Models

Community systems can achieve similar production environmental sustainability benefits as commercial aquaponics although they are not finically sustainable on their own. However, these systems can achieve greater social benefits compared to commercial systems because they actively involve community members and give them a stake in their food production. The most notable community system is Growing Power based in Milwaukie, WI and founded by urban farming advocate Will Allen. Growing Power is registered as a nonprofit organization has over 30 different revenue streams including produce and fish sales, trainings, research grants, university partnerships, and experimental production techniques such as dipping logs into the nutrient solution to grow shitake mushrooms (Smith et al., 2017) . Although committed to providing its employees adequate incomes to live comfortably Growing Power also benefits from high volumes of volunteer labor (Ezban, 2019). Although not the focus of this investigation community models should be viewed as a viable alternative method for achieving the benefits of aquaponics where financial viability is not possible. Cities and communities may wish to invest in community aquaponic systems to increase food security, empower disadvantaged communities, provide jobs, increase property values, and achieve all the environmental benefits even though the system may not directly pay for itself.

Aquaponics fits within the larger paradigm of agroecology, and provides a pathway to realize the sustainable intensification of food and agriculture. Aquaponics reintroduces biological complexity into agricultural systems, closely guided by knowledge co-creation and sharing processes that aim to maximize synergies (Fairbank, 2011). In other words, aquaponics does more, with less. More healthy fish and vegetables, more opportunity for education and empowerment, and more value, are produced with less land, less water, and fewer chemicals. Aquaponics can understand its full maintainability potential when utilized for nearby nourishment creation. These advantages can be acknowledged by any type of neighborhood nourishment generation anyway minimal, soilless frameworks, for example, aquaponics are remarkably adjusted to urban situations. By bringing aquaponics into populace focuses nourishment miles, the separation nourishment heads out from generation to utilization, are extraordinarily decreased. This decreases the non-renewable energy sources and consequent carbon discharges from nourishment dissemination. For present day farming this midpoints to 1,600 miles for vegetables and 2,400 miles for organic product, and appropriation represents 7-11% of the carbon discharges from horticulture (Andrews, 2018).

Bringing nourishment into urban territories additionally expands nourishment security. Huge urban areas are reliant on agrarian focuses hundreds or thousands of miles away and depend on interconnected systems of interstates, rail, and transporting to supply their nourishment request(Baßmann et al., 2018). Neighborhood creation builds the independence and strength of enormous urban focuses. Neighborhood nourishment creation likewise has direct advantages for the networks they are created in, particularly in the event that they are in monetarily burdened regions. Aquaponics and other types of nearby and urban horticulture can invigorate the neighborhood economies they are situated in through the formation of occupations, expanded duty income, and distribution of dollars coming into the economy. An examination that researched the monetary effects of expanding neighborhood nourishment generation to 25% of interest in the more prominent Cleveland monetary territory could make more than 27,000 new openings relating to $868 million in pay, increment local yield $4.2 billion, and increment charge income by $126 million (Rizal et al., 2018). Anyway these advantages are definitely not fundamentally low hanging products of the soil $1 billion in speculation capital would be vital alongside approach alterations and purchaser instruction (Mohrman and Parker, 2016). Network frameworks, for example, Growing Power in Milwaukie, WI encourage network cooperation and advancement through volunteer programs and renewing underutilized space (Day, 2018).

This area endeavors to indicate in more detail what might be the handy courses in which aquaculture could create in Ghana, how sensible could be the desires for development, and what could be the probable headings for national fishery supply. Plainly, market costs would need to be sufficient to give gainfulness to makers, and adequate to invigorate speculation, while not all that high that aquaculture item is excessively expensive for Ghana's shoppers (Laborde et al., 2016). Quite a bit of this situation setting will rely upon Ghana's financial development desires, populace

development, changes in GDP per capita also, the circulation of that pay. Extensively, financial development surpassing
populace development rate will increment per capita salary, and fair pay
appropriation will build buying power crosswise over wide pieces of the populace. In these conditions, request and costs for fish will increment in genuine terms and the possibilities for aquaculture can improve. Increasingly static or falling GDP per capita, or negative patterns in salary circulation will restrain possibilities for aquaculture, or will possibly allow it to create if genuine expenses of generation can be emphatically contained or diminished (Keller and MacNear, 2012).

2.13.1. Poverty Alleviation

Poverty is a global social ill that has been an issue for as long as time. Poverty as defined by the FAO is the lack of, or the inability to achieve, a socially acceptable standard of living" (Fao and Isric, 2010). Poverty is a multifaceted social ill. Some of the ills associated with poverty are unemployment, food insecurity, malnourishment and other health related conditions. The practice of aquaponics responds to poverty in the sense that an aquaponics system produces both fish and vegetation which are both rich in various nutrients that are beneficial to human health. For example, fish are rich in proteins and omega three fatty acids, vegetation is rich in vitamins and proteins. Therefore, aquaponics is an effective and progressive means of alleviating poverty by being a form of subsistent form of ensuring household food security.

At the point when utilized for neighbourhood nourishment fabricating, Aquaponics can comprehend its total supportability potential. Anyway conservative, soilless frameworks, for example, aquaponics are remarkably custom fitted to urban settings, these preferences can be acknowledged by a neighborhood food creation. The separation between nourishment making a trip from assembling to utilization is altogether diminished by bringing aquaponics into populace focuses nourishment miles. This declines nourishment dissemination non-renewable energy sources and consequent carbon discharges. This normal of 22 to 1,600 miles for vegetables and 2,400 miles for products of the soil for current horticulture represents 7-11% of the carbon emanations from farming (Bennett and Payne, 2019).

Bringing sustenance into urban domains furthermore grows sustenance security. Colossal urban territories are poor on cultivating centers hundreds or thousands of miles away and rely upon interconnected frameworks of interstates, rail, and sending to supply their sustenance demand (Laborde et al., 2016). Close by creation assembles the freedom and adaptability of huge urban core interests. Close by sustenance creation in like manner has direct benefits for the systems they are made in, especially if they are in fiscally prevented areas. Aquaponics and different kinds of close by and urban cultivating can fortify the area economies they are arranged in through the generation of occupations, extended appraisal pay, and appropriation of dollars coming into the economy. An assessment that examined the financial impacts of growing close by sustenance age to 25% of enthusiasm for the more critical Cleveland money related zone could make in excess of 27,000 new openings identifying with $868 million in compensation, increase common yield $4.2 billion, and augmentation charge pay by $126 million (Jones et al., 2015). Neighborhood sustenance age through aquaponics and various techniques can expect work in diminishing sustenance deserts. Sustenance deserts are zones where inhabitants don't approach new, healthy sustenance choices.

2.14. Food and Nutrition Security

Assuring food security in the twenty-first century within sustainable planetary boundaries requires a multi-faceted agro-ecological intensification of food production and the decoupling from unsustainable resource use. According to the current discourse, this involves an increase in productivity and resource use efficiency, solutions for small holder farmers as well as a reduction in food waste (Griggs et al., 2013). The new approach requires increasingly complex but still sustainable agricultural technologies that can raise crop yields on limited farmland, when water is getting scarce, and with little impact on climate and biodiversity (Variyar et al., 2016). Food production within a sustainability framework requires ideas that exceed traditional innovation paradigms, acknowledging the complexity arising from sustainability (Sumberg et al., 2012) In the field of food production, however, the multiplicity of relevant components makes it difficult to assess how much a technology or innovation contributes to sustainability.

Aquaponics is a rapidly emerging technology that integrates recirculating aquaculture with hydroponics (production of plants in nutrient solution, without soil) (Rakocy et al., 2004) having its origins back in the 1970's (Love et al., 2015a). Aquaponics food production is highly efficient, because it re-uses the nutrients contained in fish feed and fish waste to grow the crop plants in an ecological cycle (Kloas et al., 2015). Its potential to improve sustainability is discussed in terms of food security and as an alternative to intensive fisheries or aquaculture, by effectively managing the food-water-energy-nexus (Sumberg et al., 2012).

Essential technical components of aquaponics systems are the fish tanks and plant grow beds, while dedicated biofilters and settlers are optional and depend on the configuration of the system. The microbial community is central for the catabolism of the organic matter contained in the feces and feed residues and for the conversion of the fish-generated ammonia to nitrate (Bittsánszky et al., 2015). Fully contained and climate-controlled aquaponic systems potentially operate under water conserving and contaminant-free conditions. At its highest-level aquaponics is a technology-intensive, capital-intensive and knowledge-intensive method of food production. (Rahman, 2016). Aquaponics can understand its full maintainability potential when utilized for nearby nourishment creation. These advantages can be acknowledged by any type of neighborhood nourishment generation anyway minimal, soilless frameworks, for example, aquaponics are remarkably adjusted to urban situations. By bringing aquaponics into populace focuses nourishment miles, the separation nourishment heads out from generation to utilization, are extraordinarily decreased. This decreases the non-renewable energy sources and consequent carbon discharges from nourishment dissemination (Calthorpe, 2015). For present day farming this "Registration tracts qualify as nourishment deserts on the off chance that they meet low-salary and low-access edges:

- They qualify as "low-salary networks", in light of having: an) a destitution pace of 20 percent or more prominent, OR b) a middle family pay at or underneath 80 percent of the region middle family pay.
- They qualify as "low-get to networks", in light of the assurance that in any event 500 people as well as at any rate 33% of the evaluation tract's populace live more than one mile from a grocery store or huge supermarket (Clark et al., 2018)

("Food Deserts," In food deserts these alternatives are supplanted by enormous cheap food chains, adding to many negative wellbeing ramifications for the occupants in those networks. Creating aquaponics activities in these areas could give access to sound wellsprings of produce and protein. Right off the bat in this examination creating nations were distinguished as a social gathering that may profit incredibly from aquaponics. People and networks the same could profit from a dependable wellspring of nourishment creation anyway there are a few boundaries that make usage of aquaponics in this setting unfeasible as of now (König et al., 2016).

Aquaponics requires a genuinely enormous measure of learning to run effectively. To effectively execute aquaponics in creating nations cultivators would require broad preparing and instruction on points that might be new to them, for example, pH, supplement levels, and the nitrification procedure. Also clients would should be prepared in water methods and approach appropriate hardware.

Water Quality

Access to proper water sources might be an issue by and large where downpour water gathering isn't adequate. Neighborhood water sources may contain high turbidity levels, not meet pH necessities, or contain different aggravates that would weaken the framework. In focused on regions aquaponics could make strain between drinking water assets also, food assets (Bittsánszky et al., 2015).

2.15. Climate Change

The past twenty years have been significantly filled with carbon-intensive activities. Due to the need to grow economies internationally, most countries have used carbon-intensive means to grow their economies and this has come at a cost. The natural environment has endured the most due to natural resources being the most useful in growing economies.

Rising fossil fuel burning and land use changes have emitted, and are continuing to emit, increasing quantities of greenhouse gases into the Earth’s atmosphere. These greenhouse gases include carbon dioxide (CO2), methane (CH4) and nitrogen dioxide (N2O), and a rise in these gases has caused a rise in the amount of heat from the sun withheld in the Earth’s atmosphere, heat that would normally be radiated back into space (Victor, 2015). This increase in heat has led to the greenhouse effect, resulting in climate change. The main characteristics of climate change are increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and increases in ocean temperatures and ocean acidity – due to seawater absorbing heat and carbon dioxide from the atmosphere . The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Change, 2014) dispelled many uncertainties about climate change. Warming of the climate system is now unequivocal. It is now clear that global warming is mostly due to man-made emissions of greenhouse gases (mostly CO2). Over the last century, atmospheric concentrations of carbon dioxide increased from a pre-industrial value of 278 parts per million to 379 parts per million in 2005, and the average global temperature rose by 0.74° C. According to scientists, this is the largest and fastest warming trend that they have been able to discern in the history of the Earth (Mimura et al., 2015). An increasing rate of warming has particularly taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. The IPCC Report gives detailed projections for the 21st century and these show that global warming will continue and accelerate. The best estimates indicate that the Earth could warm by 3° C by 2100. Even if countries reduce their greenhouse gas emissions, the Earth will continue to warm. Predictions by 2100 range from a minimum of 1.8° C to as much as 4° C rise in global average temperatures (Parry, 2019).

2.15.1. CLIMATE CHANGE AND ADAPTATION

Human beings have been adapting to the variable climate around them for centuries. Worldwide local climate variability can influence peoples' decisions with consequences for their social, economic, political and personal conditions, and effects on their lives and livelihoods. The effects of climate change imply that the local climate variability that people have previously experienced and have adapted to is changing and changing at relatively great speed (Becker et al., 2011).

The major impacts and threats of global warming are widespread. Increasing ocean temperatures cause thermal expansion of the oceans and in combination with meltwater from land-based ice this is causing sea level rise. Sea levels rose during the 20th century by 0.17 metres. By 2100, sea level is expected to rise between 0.18 and 0.59 metres. There are uncertainties in this estimate mostly due to uncertainty about how much water will be lost from ice sheets (Abraham et al., 2013), for example Greenland is showing rising loss of mass in recent years. Increased melting of sea ice and freshwater influx from melting glaciers and ice sheets also has the potential to influence global patterns of ocean circulation (Munang et al., 2013). As a result of global warming, the type, frequency and intensity of extreme events, such as tropical cyclones (including hurricanes and typhoons), floods, droughts and heavy precipitation events, are expected to rise even with relatively small average temperature increases. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (Mercer et al., 2012). Climate change will have wide-ranging effects on the environment, and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity and coastal zones. Changes in rainfall pattern are likely to lead to severe water shortages and/or flooding. Melting of glaciers can cause flooding and soil erosion. Rising temperatures will cause shifts in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. Temperature increases will potentially severely increase rates of extinction for many habitats and species (up to 30 per cent with a 2° C rise in temperature).

What makes aquaponics one the most sustainable agricultural practices is its ability to save water. Albeit it may seem like aquaponics uses excessive water at first, it actually saves water in the long term as it is a recirculating aquaculture system (Martin, 2010). Globally, there is an urgent need for innovative, sustainable agricultural practices that will alleviate poverty and ensure household food and nutrition security. Aquaponics has the potential to be a key local economic development driver. If practiced and managed efficiently, aquaponics can be grow and address socio-economic issues as well as environmental issues. Some of the soico-economic issues that faced globally include, food and nutrition security, aquaponics can produce higher yields of food organically. There is also the climate change issue, of which aquaponics is an agricultural practice with no toxic soil run-off like other agricultural practices. Due to its lack of pesticide use and it being a recirculating aquaculture system, aquaponics does not have toxic run-off like conventional agricultural practices.

2.15.2. Environmental factors

There are some key contemplations in figuring out where aquaponics is generally appropriate what's more, helpful. Districts on the planet where soil richness is poor (and especially where renewing the dirt with supplements by means of natural material is troublesome as well as costly) what's more, water is rare are the perfect areas (Junge et al., 2017). Aquaponics is focused with even the most profitable customary aquaculture and agribusiness frameworks as far as water use. Aquaponics nourishment generation is incredibly water effective, as the vegetable developing strategies are soil-less. Nonetheless, to go up against hydroponics, fish–plant frameworks ought to be considered all in all so as to legitimize higher establishment costs (Goddek et al., 2015b). When mulling over these elements, semi-bone-dry locales with poor access to water would remain to profit the most from this new technique for nourishment creation. Water is a huge factor, particularly for quality norms. Aquaponics has the extraordinary preferred position of recycling water, which dodges any need to secure huge day by day volumes to make up for misfortunes. In zones where water is sloppy, debased by toxins or pathogens/parasites, aquaponics, just as RAS, is a perfect framework to upgrade fish creation, lessen mortality of sea-going creatures and improve quality. In this case, the additional speculations expected to supply little volumes of good-quality water (e.g.through downpour reap or artesian wells) can be effectively recouped by the additional worth from more excellent fish and lower death rates (Monsees et al., 2017). Saltiness levels in water are the subsequent stage in the water evaluation process. While freshwater fish can endure certain degrees of saltiness, increments in water electric conductivity (EC) over a specific levels limits the development of salt-narrow minded vegetables. This would push horticultural makers to think about just salt-tolerant species, with potential dangers of diminished benefits attributable to economic situations which may not be so responsive. Furthermore, the development of supplements and saltiness through the seasons because of lopsided characteristics between framework consumption (feed) and plant take-up could similarly carry the aquaponic units to confront expanded saltiness issues (Rawlinson and Forster, 2001). These would should be settled through moderate water dumping or adjusted administration (impediment in feed use, editing with salt-retaining plants) that may lessen frameworks' benefit or profitability and may require a more elevated level of skill in administrators.

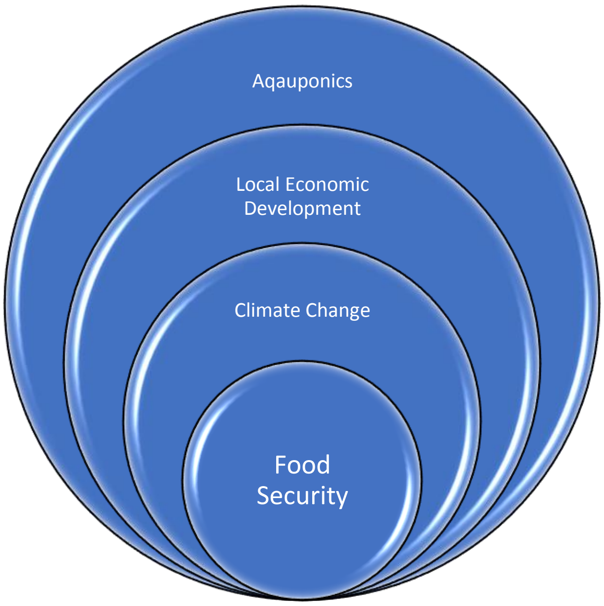
Atmosphere is another main consideration, as it will decide the additional expense for every unit to keep up the perfect ecological conditions for aquaponic nourishment generation. When all is said and done, locales where the normal day by day air temperatures during the time are 20–30°C are the perfect for tropical fish, for example, tilapia, and warmth-tolerant plants (Villamar, 2018). Consequently, the selections of yields and fish fundamentally influence the expenses if climatic control is expected to coordinate the perfect developing states of the two parts. Also, districts where normal day by day air temperatures are great, yet broadly vacillate during the day and night (for example good countries and rocky areas), would be especially tricky for fish creation. This is on the grounds that huge changes cause worry to the creatures. Consideration should likewise be paid to the seasons. Cold winter seasons will drive aquaponics ranchers to either put resources into vitality requesting warming frameworks for their nurseries or stop creation altogether for specific months. It is accordingly critical to examine the generation arrangement cautiously and perhaps discover elective species that maintain a strategic distance from useless segments of the year. Stretched out stormy seasons power ranchers to secure their units with solid overhangs or on the other hand nurseries, as huge volumes of downpour could harm crops, influence the frameworks to flood or to weaken too much the supplements in water. In any case, if from one perspective this need requires additional ventures, on the other it very well may be productive in zones where conventional farming is seriously restricted attributable to flooding or supplement spill over (Ahmed et al., 2019).

The same arrangement additionally relates to twist, as the nearness of an ensured situation could bring more significant returns and better nature of vegetable items, while customary agribusiness would battle. Summer seasons can cause water overheating. In spite of the fact that strategies to keep temperatures generally low during hot periods are very straightforward and can be upheld with legitimate framework structures, it is conceivable that water temperatures would ascend to imperfect levels during incredibly hot periods if no water cooling frameworks were utilized. This would restrict farmers’ vegetable development and determination, despite the fact that it may not influence tropical fish or nitrifying microbes.

2.16. Conclusion

Below is a concentric diagram summarising the key literature strands of this study:

Figure 9: Concentric diagram showing key literature strands of aquaponics



Source: Author, 2019

To conclude, there are numerous key factors that contribute to local economic development include food security and employment opportunities. Aquaponics is a pathway to achieving local economic development as it addresses all the above; food security and employment opportunity. Aquaponics is a sustainable, agricultural practice that possesses both subsistence and commercial potential (Laidlaw and Magee, 2016). Sustainability is key currently where climate change is affecting all spheres of development especially agriculture which is climate sensitive. Aquaponics has the potential to create employment opportunities when commercialised, and ultimately alleviate poverty.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Introduction

This chapter will explicitly breakdown the method that will be used to collect the relevant data for the study. This chapter will answer why the study will be done, how it will be done and the relevant justifications of why the chosen methods of data collection are most suited for this study. The ethical considerations will also be presented in this chapter as it is a requirement prior to collecting any data for the study. Lastly, the chapter will be summarised and specific methods of data collection will be reiterated.

This study will only make use of quantitative methods of collecting data. A quantitative approach to collecting data is suitable for this study because, a quantitative approach tests objective theory by examining the relationship among variables (Creswell, 2013). This study examines the relationship between fish and plant variables in a low-cost aquaponics system with the purpose of making a financial viability analysis. The financial viability is important to this study because it will assist aquaponics farmers or those aspiring to practice aquaponics to work out if it is a financially viable practice in terms of the input that goes into the system to produce biomass.

3.2. Aim of the study

To determine the financial viability of biomass produced in a small-scale, low-cost aquaponics system in Ndwedwe that will promote sustainable agricultural practices, increase food and nutrition security and promote local economic development.

3.3. Research Paradigm

The study will take place in KwaDeda, which is a rural community based in Ndwedwe. The climate conditions in this rural community ranged from 28 to 34 degrees during the seventeen week period of conducting the study.

The community is an African community which is still very traditional in their way of life.

3.4. Research design and methods

Plant Biomass: The plants were measured using a measuring tape consistently on a weekly basis over a period of seventeen weeks.

Fish biomass: The fish biomass was randomly sampled in groups of five from each tank (three tanks).

- The five fish in each tank were weighed.
- This process was repeated five times in each tank
- Then an average weight was calculated in each tank
- 5 fish(5) = X
- X /5= Average weight

The financial viability of each input variable in the small-scale, low-cost aquaponics system was calculated using the following method which was derived from the FAO (2014) paper on calculating the financial viability of biomass output in a low-cost aquaponics system:

- Electricity: 30W (water pump) + 5W (air pump) × 24hours (daily) ×30 days (monthly) ÷ 1000 = 25kWh per month.
- Water: Water did not have costs, however fifty litres were replenished weekly from rain harvested water.
- Fish feed: 50g (fish feed) × 3 (tanks) × 30 days (monthly) = 4.5_kg per month.
- Miscellaneous: The miscellaneous costs were the pH buffer which was used during the course of the study (seventeen weeks).

Every aquaponics system is composed of the following components:

- Fish tanks
- Hydroponic units
- Pump
- Sump tank (may not be present in small systems)

The costs of the structural components are excluded from the financial viability analysis.

3.6. Population

This study monitored fish and plant performance in a low-cost aquaponics system only. The fish that were used in the low-cost system were Mozambican tilapia and the plants that were used were separated into two categories; leafy vegetables and fruity vegetables. The purpose of categorising the plants was to monitor the performance between the two and prove whether fruity or leafy vegetables are more suited to low-cost aquaponics systems or not.

The leafy vegetables that were used in the system included; parsley, basil, spinach, lettuce and cabbage. The fruity vegetables included; tomatoes, beetroot, pepper and chilli.

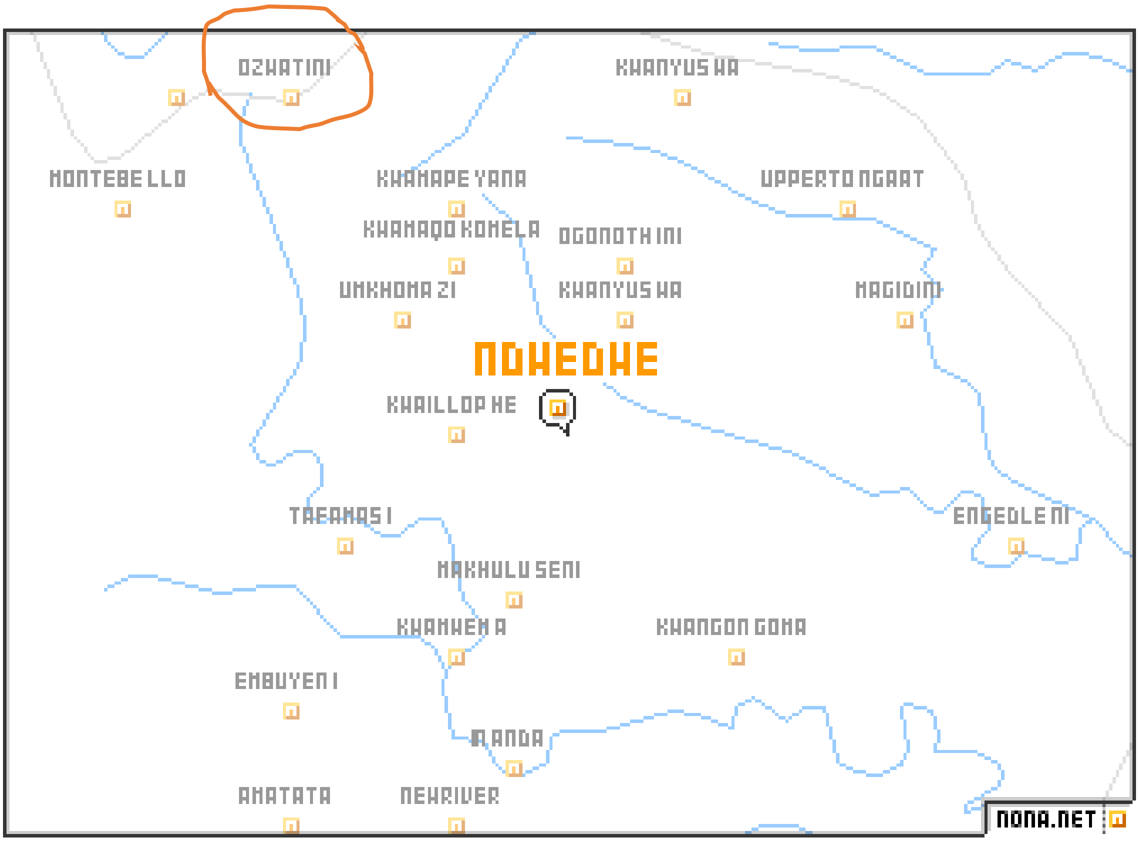
The seedlings were planted in the low-cost system on the 11th of June 2019. The seedlings were twelve days old according to Sunshine Seedlings where they were purchased. The seedlings were planted the same day they were purchased. The fingerlings however were delivered on the 10th of June 2019 from an aquaculture farm in Port Edward. Between the 10th of June and 12th of June 3 fingerlings died. This was due to stress from the long journey from Port Edward to Ndwedwe.

All together the number of fingerlings that were added to the system were 330. The low-costs aquaponics system on the site had three fish tanks and 110 fingerlings went into each tank. The fingerlings varied in size and length but according to the aquaculture farmer who delivered them they were all six months old. There were six grow beds and each grow bed had an average of twenty-one seedlings planted in it.

3.5. Setting

SITE: KwaDeda- Ndwedwe

Figure 10: Map showing Ndwedwe



Source: https://nona.net/features/map/placedetail.1016020/Ndwedwe/

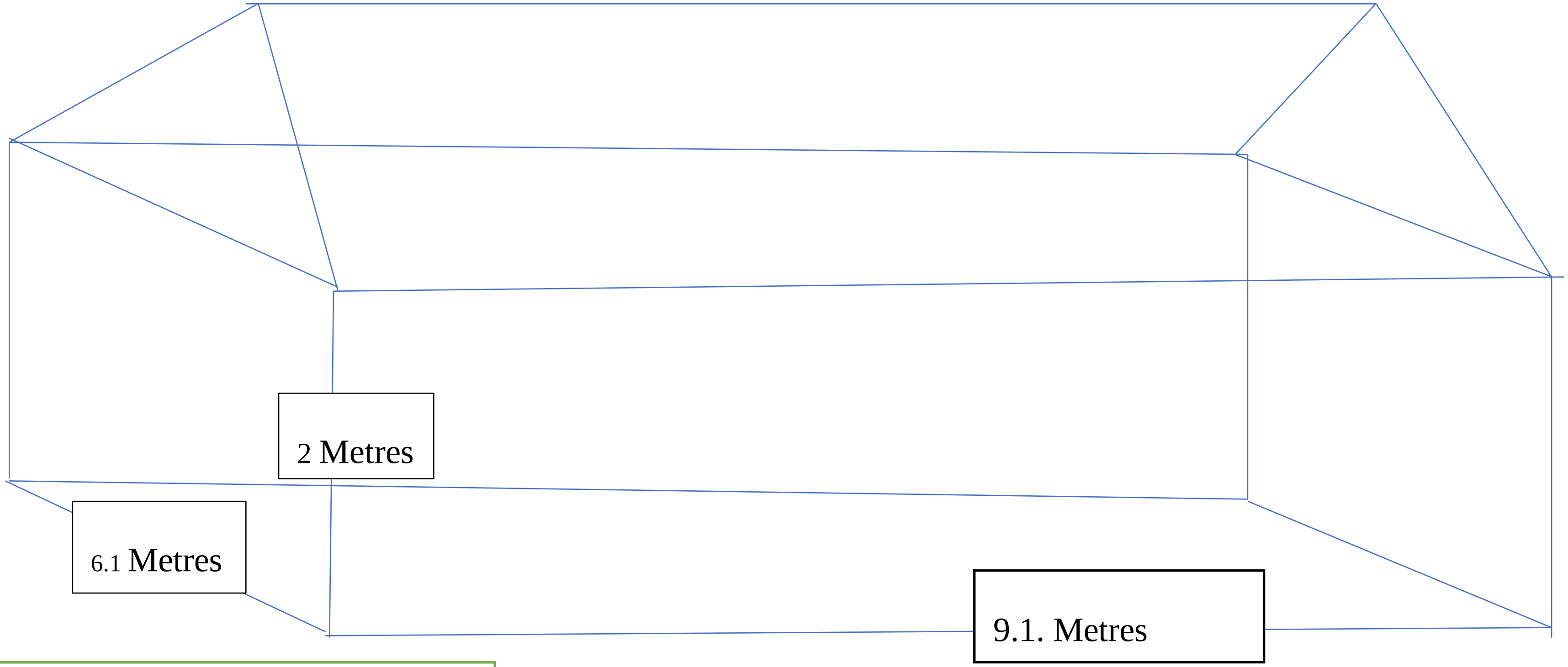
Above is a map of Ndwedwe where the low-cost aquaponics system is based in a small community called Kwa-Deda which is in the Ozwatini vicinity of Ndwedwe. The system is located 35km North East of Wartburg at the homestead of Mr Philani Ngcobo. Ndwedwe is of a mostly adulated topography and Kwa-Deda is about 947km above sea level. The general climate conditions in this area are hot during the day reaching 32 degrees Celsius on average and cold during the night dropping to 7 degrees Celsius on average. The whole area of Ndwedwe is an arid area as there is limited access to water. This proved to be problematic at the site as the evaporation rate was high during day because of the high temperatures and there was very little or no rainfall.

Aquaponics is a farming method that is impossible without water. Although it is a sustainable practice that saves water compared to conventional farming methods, it still does need to be replenished now and again due to evaporation. The homestead on which the system is situated does not have running water but Mr Ngcobo has setup water storage tanks in his yard to capture rain water which he uses to water the plants that he has planted in the field within his homestead and replenish the water in the low-cost aquaponic system. The amount of water he uses to replenish the system on a weekly basis on average is 25litres. However, with the current drought that Ndwedwe is undergoing, Mr Ngcobo is replenishing up to 50 litres a week which is twice the amount he usually adds.

Below is a schematic diagram of the tunnel area where the aquaponics operation was set up.

Tunnel Area:

Figure 11: Schematic diagram showing growing tunnel



Source: Author, 2019

3.7. Sampling Method

Fish Sampling

The fish were handled by a PhD student from the school of life sciences who has been trained for fish handling.

Method for sampling fish: Random

Steps for weighing fish

1) A small bucket was filled with water (10 litres) with water from the aquaponic system.
2) The bucket with water was then placed on the scale and tared.
3) Five fish were scooped from the tank and put in the bucket of water on the scale
4) The weight was recorded
5) This was repeated 5 times
6) Divide this figure by 5 to retrieve an average weight for each fish.
7) The whole process was repeated for all three tanks

Image 1: Image showing measuring apparatus

Source: Author (2019)

Plant Sampling: Plants were tagged in each of the tanks. One of each type that was planted (Beetroot, parsley, pepper, cabbage, chilli, basil, tomatoes and spinach).There were six tanks all together and 30 plants tagged altogether. The growth of these plants was measured over a seventeen week period with a measuring tape.

3.9. Construction of the instrument

This study only made use of quantitative methods of collecting data. A quantitative approach to collecting data is suitable for this study because, a quantitative approach tests objective theory by examining the relationship among variables (Creswell and Creswell, 2017)This study examines the relationship between fish and plant variables in a low-cost aquaponics system with the purpose of making a financial viability analysis. The financial viability is important to this study because it will assist aquaponics farmers or those aspiring to practice aquaponics to work out if it is a financially viable practice in terms of the input that goes into the system to produce biomass.

3.10. Data Collection

- This study monitored and measured the biomass output, which included fish and plants in a low-cost aquaponics system situated in KwaDeda which is a small community in Ndwedwe.
- Leafy and fruity vegetables (biomass) that were planted in the aquaponics system were weighed and measured. The plant biomass (spinach, cabbage, lettuce, basil, pepper, chilli, tomato, beetroot and parsley) was measured in height on a weekly basis using a measuring tape. The day of the week on which the plant biomass was on random days of the week. The fish biomass was not measured or weighed, however, the number of fish that were in the system were monitored.

Image 2: Image showing deep water culture in Ndwedwe

Source: Author (2019)

Image 3: Image showing gravel bed in Ndwedwe

Source: (Author, 2019)

- To determine the financial viability of aquaponics in Ndwedwe, the operation of an aquaponics system based on the UVI mode was analysed. Due to the climate conditions and recommendations acquired from literature, it was best to use a financial viability analysis to analyse the plant biomass of the low-cost system as it assisted calculating the market-value of the plant biomass for the purpose of working out financial viability.

- The analysis was based on but not limited to methods put forth by (Engle, 2016) paper *Economic Analysis of a Commercial-Scale Aquaponic System for the Production of Tilapia and Lettuce.* As discussed in the following sections, cost and revenue analyses were used to develop enterprise budgets for the individual production of tilapia, lettuce, basil, beetroot, cabbage, tomatoes, pepper, chilli and parsley with break-even prices calculated for each crop. The biomass production costs from the low-cost aquaponic system were predicted to be slightly lower than conventional methods as there were no labour costs or heating and lighting costs which usually increases the production costs exponentially.

3.11. Data Analysis

- A financial viability analysis was performed in order to determine specific costs associated with the fish and plant components in the system. The values of both the fish and plant components in the system were combined to determine the costs of producing the biomass output in the system.

- Determination of Direct Costs
  The direct costs associated with the plant and fish biomass were the costs that were incurred as a result of components that were directly added to the system but not joined or part of the infrastructure or any fixed structure of the low-cost system. These costs involved; fish feed, fingerlings, seedlings, lime stones and pH up buffer the pH levels of the system.

Table 1: Table showing direct costs in an aquaponics system

Direct Costs	Unit	Quantity	Total Costs
Fingerlings			
Seedlings			
Fish Feed			
Gravel Stones			

Floating beds & Baskets			
Water			

Source: Author (2019)

3.12. Reliability and Validity of the study

The study is reliable because the method of data collection was consistent over a seventeen week period. The time and location at which the data was collected was consistent and data was captured consistently, using academically informed methods.

3.12.1. Environmental control

To optimise the small-scale, low-cost aquaponics system in Ndwedwe, additional structures were implemented to ensure efficient operation of the system. Due to temperatures being too low for Tilapia fish, a low-cost heating method that was used was geyser blankets and adding 75 litres to the system daily (25litres*3 buckets) of fire heated water to the system. This was due to the fact that the average water temperatures in Ndwedwe were too low for Tilapia fish (about 18 degrees Celsius). The ambient air temperature however, averaged at 28 degrees during the day and dropping drastically to about 7 degrees Celsius. UVI researchers found that water temperatures higher than 28 degrees Celsius resulted in fish mortality brought on by an unidentified bacterial pathogen (Rakocy et al., 2006). The biggest challenge in this study was raising the water temperature to 26 degrees or above which is the optimum temperature for Tilapia to thrive.

Raising the temperature in the system came with the risk of killing the plant vegetation as some of it does not respond well to heat. This was one of the cons of having a closed, low-cost system because whatever one controlled in either of the fish or plant components, the other was inevitably affected. However, the heating methods that were used to raise temperatures (geyser blankets, boiling water added to the system) were not as intensive and effective as other heating systems.

Other studies have shown that in hydroponic growing conditions, the air temperature may exhibit a wider range than traditional farming methods will allow. Lee and Takakura found that spinach may be successfully grown in temperatures as high as 33 degrees Celsius, given that the root-zone temperature is maintained at a range between 22 degrees Celsius and 26 degrees celsius (Rakocy et al., 2016). Alternately, (Rakocy et al., 2006) found that hydroponic plants could be successfully grown at temperatures as low as 13 degrees Celsius, given the root-zone temperature is maintained at 24 degrees Celsius. The temperatures that are optimal for Tilapia fish growth in South Africa vary from 24-28 degrees celsius, in order to achieve optimal fish, bacterial and plant growth. However, this was not possible as this was a low-cost system and additional heating would have equated to additional costs.

There was a need for environmental control at the sight in order to optimise the water temperature for the fish because the temperatures were too low. The average ambient air temperature during the data collection period which was from the 24th of May 2019 to the 24th of August 2019 was 28 degrees Celsius and the average temperature during the night was 8 degrees Celsius. The average water temperature in the low-cost aquaponic system averaged at 18 degrees during the day and 10 during the night which is significantly low for Tilapia fish species to grow to their optimum size. Low water temperatures stunt the fish growth and can also potentially stress the fish which could lead to them dying. This could eventually result in the collapse of the low-cost aquaponic system. Since this was a low-cost system, there were limitations in terms of expenditure on variables that could have optimised the system. These variables included heating systems to increase ambient air temperatures and water temperatures for the fish and investing in better filtration systems to improve water quality. However, the heating costs were kept at minimum and

WATER TEMPERATURE AND QUALITY CONTROL

As indicated before, water temperature was the biggest hurdle in this study as it desperately needed to be increased for the fish to grow in an optimum environment. The water temperature was low because, South Africa in general does not meet the optimum temperature requirement for Tilapia (Mchunu et al., 2018). Ndwedwe is also generally a cold area and the data was being collected during the winter season. During the day, the temperatures do increase to about 30 degrees Celsius inside the tunnel even though it is winter and they plummet to 7 degrees at night time.

Several retailers of agricultural and aquaculture equipment were contacted within the Pietermaritzburg and Howick area regarding the challenge of raising the water temperature for the fish. The need to maintain the system at low-cost resulted in the use of an unconventional heating method for the fish component of the system and that was suing geyser blankets to wrap the fish tanks as heat insulators. A heat/thermal pump was not viable cost wise as it would require excessive amounts of electricity and maintenance that geyser blankets do not require. The changes in temperature in the fish tanks were not evident immediately compared to electrical heating which would have been effective in a short space of time.

The challenges that were associated with the lack of heat in the fish tanks were not only limited to the fish, but they were also affecting the bacteria in the system which was necessary to breakdown the fish waste in order for the plants to absorb nutrient better, as a result there was a nitrogen overload in the system which could have potentially compromised the fish mortality significantly.

The water that was used in the system was harvested from the rain and stored in the water storage tanks. However, due to the fish waste and the lack of optimum conditions for the low-cost system, water quality was reduced and this was evident in the hydroponic section of the system where the plants were yellow in colour due to the lack of nutrients and deteriorating water quality.

3.13. Bias

There was no bias during the course of this study as the study was addressing unknown variables such as a small-scale, low-cost aquaponics system. The financial viability analyses that are known, have been calculated using commercial scale models. Therefore, the financial viability analysis of the biomass output in a small-scale, low-cost aquaponics system was not leaning towards a desired outcome but it was solely experimental and the outcome was unknown.

SUPPLEMENTAL WATER

The location of Ndwedwe may be in close proximity to the coast, however, there is severe water shortage in the whole area of Ndwedwe. Water is key to the effective running of an aquaponics system (Bach et al., 2013). Although, aquaponics is a sustainable agricultural practice, water is an integral part of the system because without it, the system cannot function at all. Supplementing the water in the system became a frequent exercise for Mr Ngcobo because of the drought and the rapid evaporation rate during the day because of heightened temperatures. Supplemental water was not an extra cost to the overall financial viability of the system as the water was harvested from the rain and stored in water storage tanks. The water shortage issue reached extreme levels when the water ran out in the water storage tanks because, it called for water to be collected from the nearest river which is uMkomaas. As a result, maintain the system then became labour intensive because Mr Ngcobo had to fetch water with 25 Litre buckets from the nearest river in order to supplement the water in the system.

FINGERLINGS AND SEEDLINGS

With the aquaponic system in full operation, the plant biomass which was planted on the 24th of May 2019 was set to be harvested within 8 weeks depending on the operation of the low-cost aquaponic system. The fish biomass was not to be harvested as there was still not sufficient knowledge and research done on whether the local people of the Kwa-Deda community would eat fish reared in a low-cost aquaponic system or not.

The grow beds in the system were a combination of floating beds and gravel beds. All together there were six growing beds and three fish tanks. The seedlings that were planted in the growing beds were also sporadically planted. This was because, one of the outcomes that were analysed in the study was the growth patterns of the combination of leafy and fruity vegetation in both deep-water culture and in gravel media-based grow beds.

OTHER INPUTS: FISH FEED, IRON CHELATE, POTASSIUM HYDROXIDE, CALCIUM HYDROXIDE, PH UP

In addition to supplying fingerlings and seedlings, other primary inputs are necessary for the successful operation of the low-cost aquaponics system. These include: fish feed, iron chelate, potassium hydroxide and calcium hydroxide. Fish feed serves the dual purpose of supplying nutrients and energy for fish growth, with the byproducts being utilized for plant growth. Iron must also be added to the system as iron is essential to optimal plant growth but is not supplied by aquaculture waste production (Aguilara-Titus et al., 2014). During the process of nitrification, pH is consistently being lowered, therefore the occasional addition of a base is necessary in order to raise the system pH. Potassium hydroxide and calcium hydroxide each play dual roles in both providing essential nutrients for plant growth and maintaining optimal pH throughout the system.

As reported in(Love et al., 2015a)., the optimum daily feed to plant growing area ratio for tilapia and leafy vegetation was determined to be 57 grams of feed per square meter of hydroponic growing area. This ratio results in an approximate feed requirement of 4,452 kg (9,815 lbs.) per year. Prices for these items were found at an agricultural retailer in Pietermaritzburg who stocks agricultural products.

3.14. Ethical Considerations

With any study, it is imperative to consider the ethics of the study before conducting it (Miller et al., 2012). This study solely used a quantitative approach of collecting the data, therefore it was exempt from ethics review. This means that, there were no people which were interviewed or surveyed in order to collect data for this study. The data was collected by solely collected by the author using quantitative methods.

3.15. Summary

To conclude, this study made use of a quantitative approach of data collection. The variables that were measure included; fish weight by using random sampling in each tank and the plants were measured weekly for growth in height. Then financial viability was calculated using a financial viability analysis.

3.15.1. Greenhouse structure

A variety of methods could be used to maintain optimal air and water temperature. As water interacts directly with the fish, bacteria and plants, maintaining optimal water temperature is very important for the success of an aquaponic system. Water temperature can be best controlled through the use of water heaters or by holding the air temperature at the optimal level. However, the study area did not have heaters as it was a small-scale, low-cost operation. The aquaponics system was setup in a greenhouse, which helped with keeping the air and water temperature at a moderate level (16 to 20 degrees), however, it was still too low for the aquaculture component of the operation.

3.15.2. Determining local market price

Local market price data was obtained using the local eThekwini municipality online database on local food prices. The prices varied locally depending on the supply and demand. Although, there is no formal fish market in the study area, there is a demand for Tilapia because locals do go to the river to fish. The river is within a walking distance from KwaDeda, the study area.

MARKET VALUE OF TILAPIA

Table 2: Table showing market value of Tilapia

Area	Cost-Price (ZAR)/kg	Selling Price (ZAR)/kg
Wartburg	45	55
Ozwatini	40	45
Pietermaritzburg	42	55

Source: Author (2019) and http://www.durban.gov.za/Online_Tools/Pages/Fresh_Produce_Price_Reporting.aspx

CHAPTER FOUR: RESULTS

4.1. Introduction

This chapter will present the results of the study which were collected using quantitative methods such as measuring the plant growth in the low-cost, small scale aquaponic system and also using secondary data that was collected by a PhD candidate who has ethical clearance for fish handling. A comparative and correlation analysis was used to compare and analyse the results of the study and find common threads and themes in relation to the literature base of the study.

4.2. pH Results

This section will report on the pH results and implications that these results had on the study and making conclusions on the financial viability of the study.

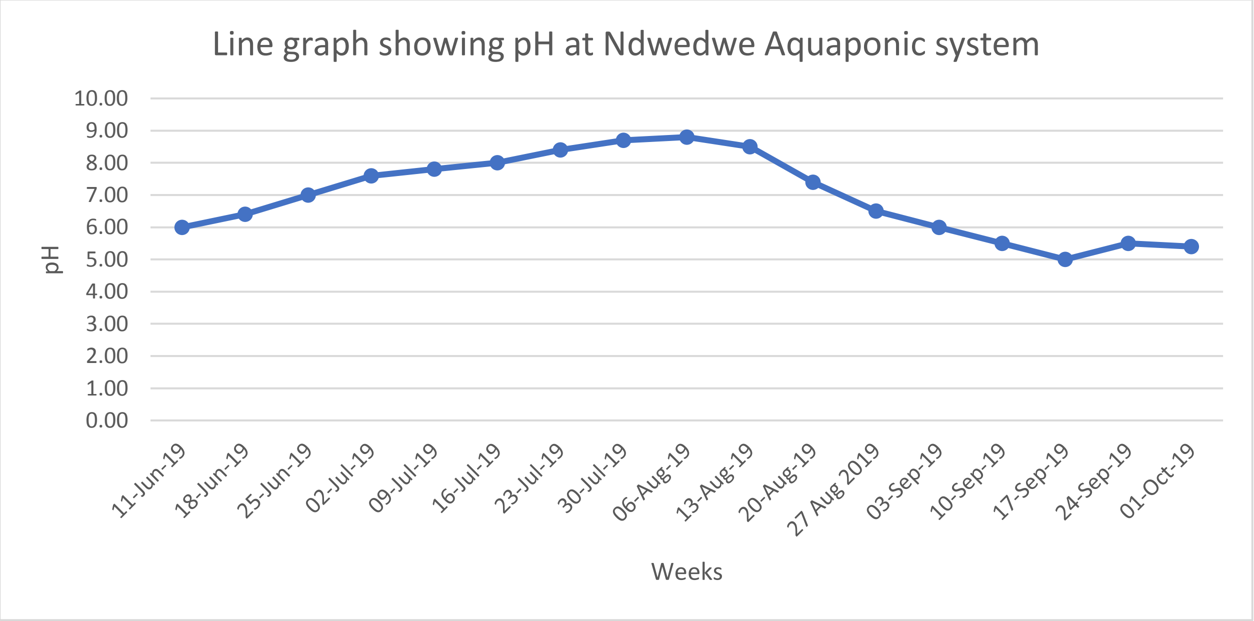
4.2.1. Balancing pH with buffers or bases

pH proved to be the most challenging variable during the course of the study as it had erratic patterns. In the event that the pH level dips under 6.0, it is important to include a base as well as increment carbonate hardness. Ordinarily utilized bases are potassium hydroxide (KOH) and calcium hydroxide (Ca(OH)2). These bases are solid, and ought to be included similarly as acids; consistently change pH gradually. Nonetheless, a more secure and simpler arrangement is to include calcium carbonate (CaCO3) or potassium carbonate (K2CO3), which will increment both the KH and pH (Sace and Fitzsimmons, 2013). There are numerous organic means of balancing pH in an aquaponic system. Some of the low-cost, organic methods of balancing pH is to add crushed seashells or egg shells to the system, limestone or adding chalk.

The recommended strategy to gradually reducing and balancing pH is to suspend porous sacks with limestone or crushed shells into the system. The pH should then be monitored daily and once it buffers above 7, the suspended sack can then be removed. In the case where sea shells have been used, it is vital to ensure that they have been flushed of all salt residue that may have remained on the shells because, salt can cause the pH to spike and destabilise the system (Suhl et al., 2016). The decision of bases to use to balance the system pH is also dependant on the type of plant biomass which is planted in the system because, some plants do not respond well to bases that are added to the system in order buffer the pH (Tyson et al., 2004) .This study used an organic pH buffer to balance the pH when it spiked. This organic buffer entailed macronutrients such as calcium carbonate, potassium carbonate and potassium hydroxide which balanced the pH gradually over a period of three days.

Below is a line graph showing the pH patterns during the course of the study.

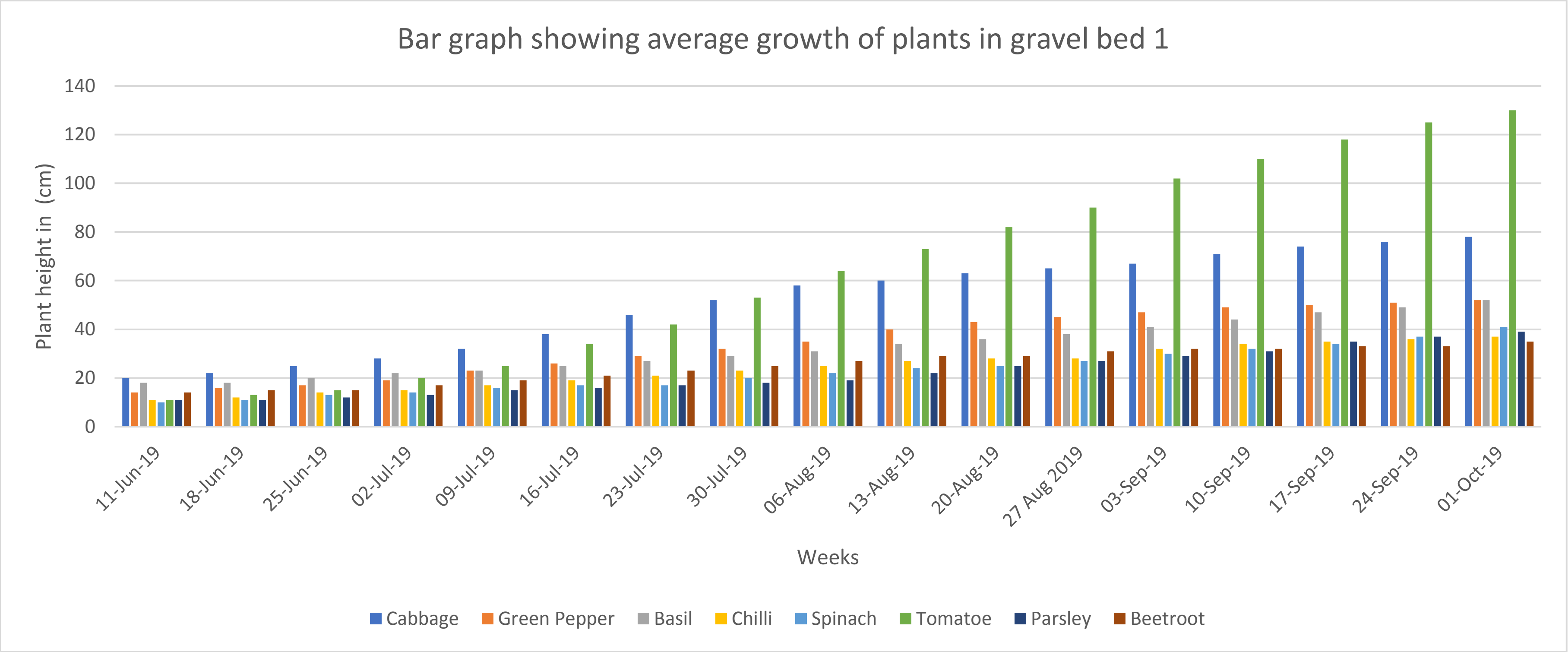
Figure 12: Line graph showing pH levels



Source: (Author, 2019)

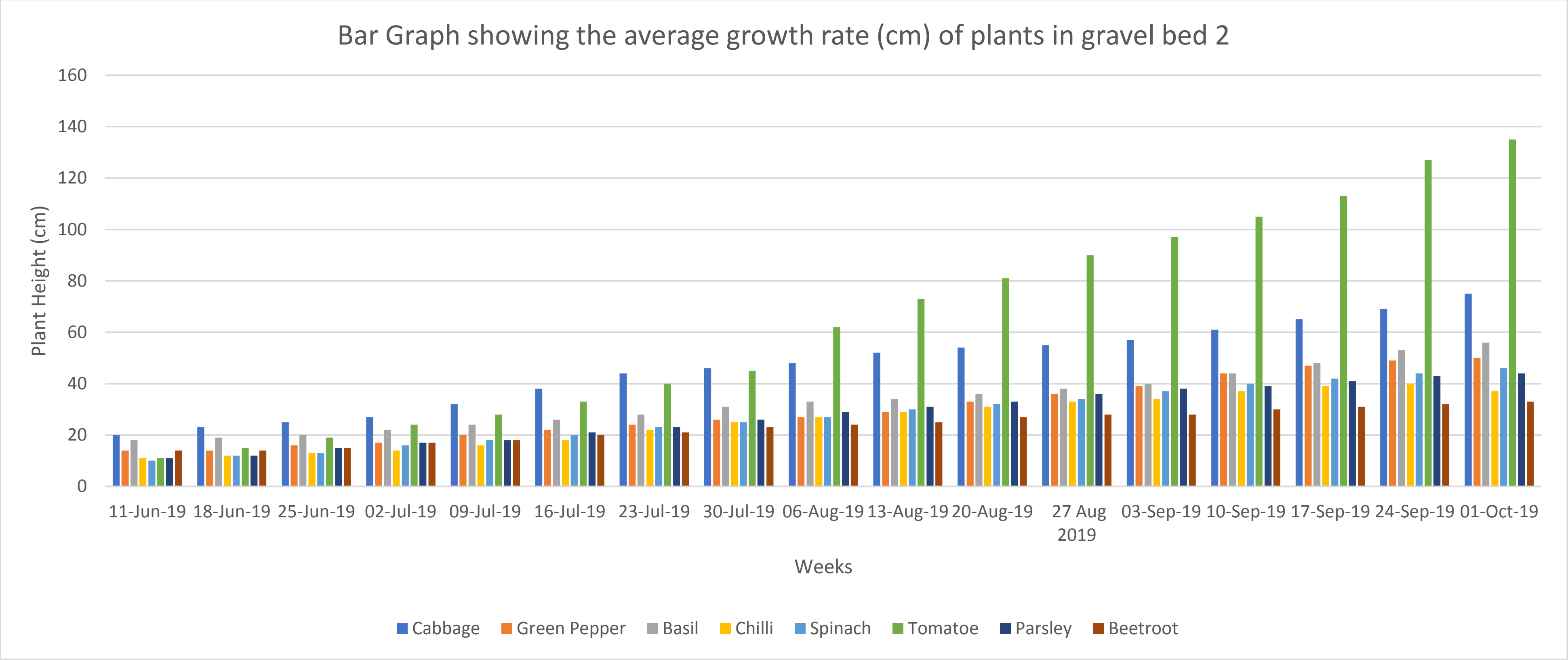
The pH started of stable at the beginning of the study but gradually increased. This can be alluded to the fact that the small-scale system in Ndwedwe was not stocked with fish yet, therefore there was no fish waste that needed to be filtered and broken down in the system. However, the plants that were planted before the fish were stocked began to show nutrient deficiency in the second week of the study.
Fish were stocked in the third week of the study. The pH began to rise steadily after that due to the system having fish. At first, the reason for the rise in pH was not fully known, but the hypotheses was the low temperatures in the fish tanks, the fish feed or challenges with the biofilter in the system. After extensive research, the system was flushed out and cleaned, the fish feed was reduced from 30 grams a day to 15 grams a day for all three tanks and a pH buffer (Image 15) was purchased to help balance the pH as pH can kill the fish in the system if not addressed urgently. After implementing all the before mentioned interventions, the system was stable and so was the pH.

Figure 13: Bar graph showing average biomass growth in gravel bed 1



Source: Author (201

Figure 14: Bar graph showing biomass growth in gravel bed 2



Source: (Author, 2019)

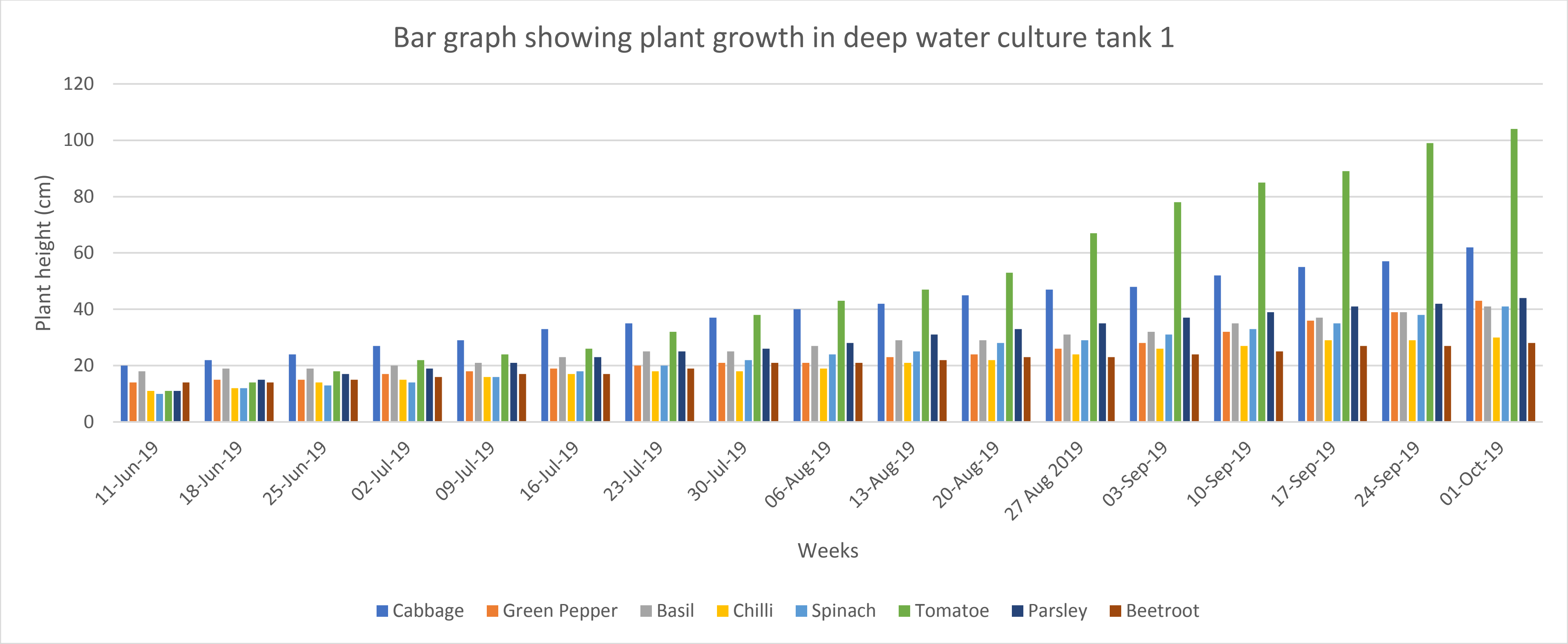
4.3. Plant growth: Gravel Bed

Figure 13 and figure 14 illustrate the growth rate of the plant component of the small-scale, low-cost aquaponic system in Ndwedwe. The presentation of the graph depicts the eight types of plants that were planted in the aquaponics system and their growth rate in centimetres over a period of seventeen weeks. The plant biomass grew steadily over the seventeen week period which is indicative of objective two, which sought to determine the growth of he plant biomass component in the small-scale, low-cost aquaponics system in Ndwedwe.

Later (in chapter six), the study will present the implications the factors affecting plant growth have on the financial viability of the biomass output. The plant growth in the aquaponics system was significant in comparison to the plant growth of the biomass that was planted in the field (figure 19). This can be alluded to the drought that Ndwedwe was experiencing during the course of the study. The growth rate of the plants that were planted inside the tunnel in the small-scale, low-cost aquaponics system was significantly better than the growth rate of the biomass that was planted in the field.

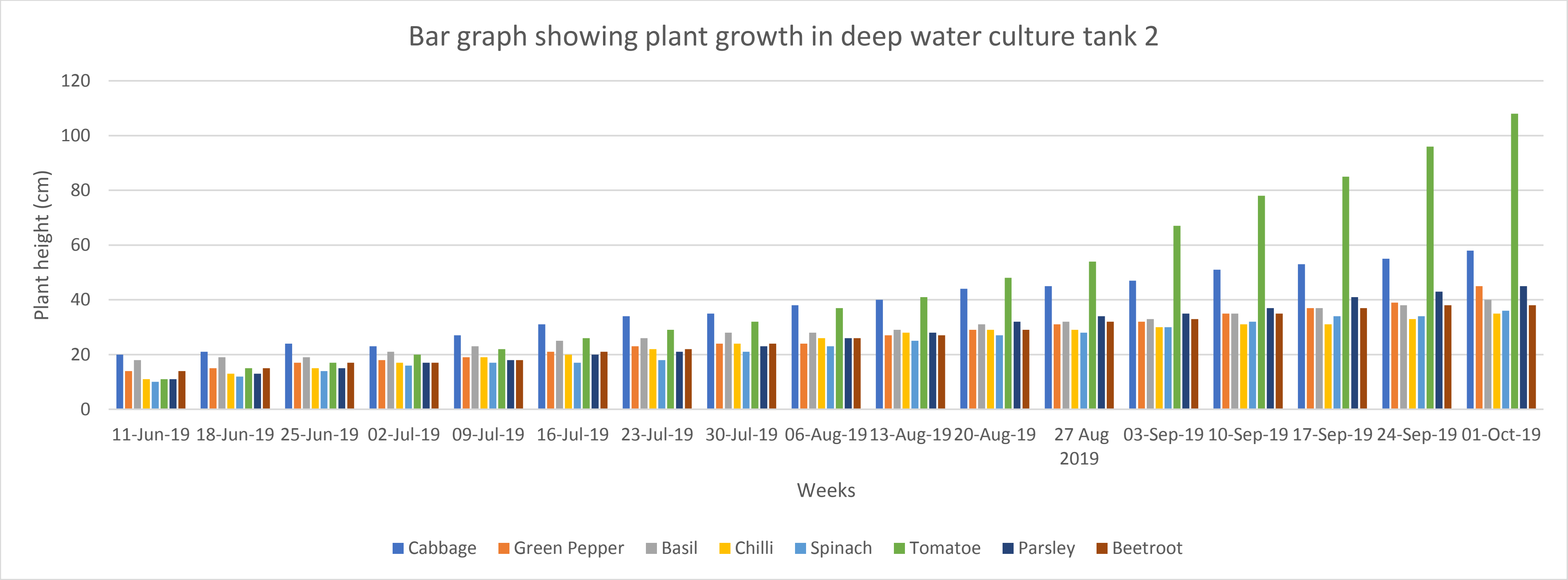
There are numerous factors that affect the growth rate of the biomass output in an aquaponics system, they include; temperature, pH, fish stocking density, feed conversion ratio of fish, nutrient flow in the system and the planting density (Buzby and Lin, 2014). The results of the study show that the growth rate of the biomass, albeit it was good but it did not reach its full potential as there were challenges with the pH, low temperatures and the feed conversion of the fish in the system .

Figure 15: Bar graph showing biomass growth in DWC 1



Source: (Author, 2019)

Figure 16: Bar graph showing biomass growth in DWC 2



Source: Author (2019)

4.4. Plant growth: DWC

The plant growth in the DWC tanks was good, however not great as it did not reach the expected height and overall growth. The system experienced challenges with the DWC component as the plants in the DWC tanks were stunted in growth compared to the plants in the gravel beds. The bar graphs present the comparisons (Figure 13 to 16), the plant biomass in the gravel beds grew better and faster than the plant biomass in the DWC. (Bittsánszky et al., 2015) suggests that the possible problem was that plants that were planted in the DWC were not suited for the DWC grow medium. In aquaponics farming, it is important that plant biomass is planted accordingly in order to yield the best results. Another suggestion that (Bittsánszky et al., 2015) was that nutrients may not be broken at an acceptable rate, and this can stunt growth and cause deficiencies in the plant biomass. The lesson that can be learnt in this study is to practice companion planting, where planting is not random but rather strategic.

4.2.2 Tunnel versus field

Plants were planted in the field concurrently as those that were planted in the small-scale, low-cost aquaponics system. This was for the purpose of addressing objective four of the study which is to determine the factors that affect financial viability of the biomass output in a small-scale, low-cost aquaponics system. Below is image 4 and 5 which shows the results of cabbage at the end of a seventeen week period. The cabbage was amongst the few plants that survived outside in the field as there was a severe drought in Ndwedwe, therefore plants were dying. The results below are indicative of the need for small-scale, low-cost aquaponics systems to be set up in homesteads (like Mr Ngcobo's) where the study was conducted. Albeit, aquaponics is a water-intensive practice, it is a circulatory system, whereby is recycled. Rain water was harvested for this study before the study began, therefore no costs were incurred to fill up the aquaponics system.

Image 4: Image showing cabbage planted in field

Source: Author (2019)

Above is an image of cabbage that was planted outside in the field. The cabbage had barely sprouted and was showing signs of stunted growth and pest infections. The slow growth can mostly be attributed to the lack of water in Ndwedwe during the course of the study. The following image, shows a picture of cabbage that was planted concurrently as cabbage that was in the field. The difference is significant albeit, both the tunnel and field are in the same location but due to the controlled environment of aquaponics, the results are different.

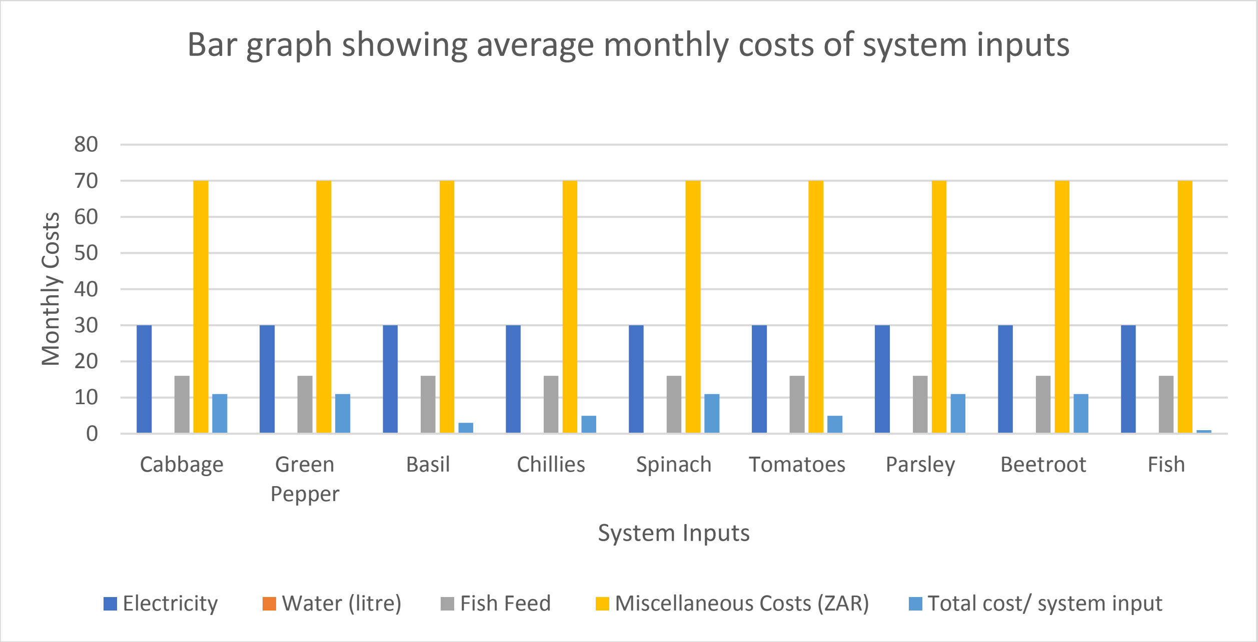
Image 5: Image showing cabbage planted in tunnel

Source: Author (2019)

Above is the cabbage that was planted in the small-scale, low-cost aquaponics system. Both cabbages (Image 4 and 5) were planted at the same time on the same day. They are both seventeen weeks old. However, the cabbage in the aquaponics system has done better than the one planted in the field. This is due to water and other nutrient factors. The cabbage outside was exposed to drought conditions whereas the one in the aquaponics systems experienced favourable conditions.

4.6. Costing: Financial Viability Analysis

Figure 17: Bar graph showing average monthly costs of system inputs



Source: Author (2019)

Above is a bar graph depicting the input costs of running the small-scale, low-cost aquaponics system in Ndwedwe. There were no costs for the water as the water was harvested from the rain before the study began.

Electricity: 30W (water pump) + 5W (air pump) × 24hours (daily) ×30 days (monthly) ÷ 1000 = 25kWh per month.

Water: Water did not have costs, however fifty litres were replenished weekly from rain harvested water.

Fish feed: 50g (fish feed) × 3 (tanks) × 30 days (monthly) = 4.5_kg per month.

Miscellaneous: The miscellaneous costs were the pH buffer which was used during the course of the study (seventeen weeks). Albeit, the graph shows the miscellaneous costs as the highest, the costs were still below one hundred South African rands.

4.7. Plant biomass growing conditions

The hydroponic component of aquaponics is where the plants are grown. The plant biomass requires certain growing conditions in order to thrive. These growing conditions include; optimal temperatures, fish to plant ratio, optimal water quality and suitable companion planting.

4.7.1. Peppers

Peppers thrive in the following growing conditions:

pH: 5.5 to 6.5
Plant spacing: 30 to 60cm (3–4 plants/m2, or more for small-sized plant varieties)
Seed germination time and temperature: 8 to 12 days; 22 to 30°C (seeds will not germinate below 13°C)
Growth time: 60 to 95days
Temperature: 14 to 16°C night time, 22 to 30°C daytime
Light exposure: full sun
Plant height and width: 30 to 90cm; 30 to 80cm (Somerville et al., 2014)
Recommended aquaponics growing medium: media beds

Growing peppers in aquaponics: There are different types of peppers, all ranging in colour and taste, yet from the sweet chime pepper to the hot bean stew peppers (jalapeño or cayenne peppers) they are suitable for being grown in an aquaponics system. Peppers are more suited to gravel beds as they thrive more than they do in DWC. This is due to the fact that DWC requires support when the peppers blossom and often they break due to the lack of support in the DWC.

Developing conditions: Peppers respond to warmer temperatures (22 to 34 degrees) Therefore, they did very well in the tunnel where the small-scale, low-cost aquaponics system was placed. This was mostly because the tunnel was always warms. (Somerville et al., 2014).

Seeds struggle to germinate in temperatures less than 15 degrees celsius. Daytime temperatures of 22–28 °C and evening time temperatures of 14–16 °C support best fruiting conditions under an overall stickiness of 65–60 percent (Miličić et al., 2017). Ideal temperatures at root level are 15–20°C. When all is said in done, air temperatures underneath 10–12°C stop plant development and cause strange disfigurement of the organic products, making them unmarketable. Temperatures less than 30–35°C lead to flower premature birth or aftermath. By and large, spicier peppers can be acquired at higher temperatures (Rakocy et al., 2016). The top leaves of the plant secure the natural product hanging beneath from sun exposure. Similarly as with other fruiting plants, nitrate underpins the underlying vegetative development (ideal range: 20–120mg/liter) yet higher convergences of potassium and phosphorus are required for blossoming and fruiting (Suhl et al., 2016). Developing directions: Transplant seedlings with 6–8true leaves to the unit as soon as night temperatures settle above 10°C. Bolster thick, overwhelming yielding plants with stakes or vertical strings dangling from iron wires pulled on a level plane over the units. For red sweet peppers, leave the green organic products on the plants until they age and turn red. Pick the initial couple of blooms that show up on the plant so as to energize further plant development (Soto et al., 2008). Decrease the quantity of blooms in case of extreme organic product setting to support the developing natural products to arrive at satisfactory size.

Harvesting: The peppers began to be harvested after fourteen weeks as they had reached a marketable size.

Peppers can be easily stored fresh for 10_days at 10_°C with 90–95_percent humidity, or they can be dehydrated for long-term storage (Somerville et al., 2014).

Below is an image of peppers that are at a harvesting stage at the small-scale, low-cost aquaponics system in Ndwedwe. The peppers that were planted in the field died due to the drought. Albeit, peppers thrive in warmer conditions, the drought caused temperatures to exceed 34 degrees at some point and there was no water to hydrate the plants, hence they died. However, the peppers that were planted in the small-scale, low-cost aquaponics system in the tunnel did well by the end of the seventeen week period.

Image 6: Image showing green peppers at harvesting stage

Source: Author (2019)

4.7.2. Tomatoes

pH: 5.5–6.5

Plant spacing: 40–60_cm (3–5_plants/m2)

Germination time and temperature: 4–6_days; 20–30_°C

Growth time: 50–70_ days till first harvest; fruiting 90–120_ days up to 8–10_months (Rakocy, 1997)

Optimal temperatures: 13–16°C night, 22–26°C day

Light exposure: full sun

Plant height and width: 60–180_cm; 60–80_cm (Rakocy, 1997)

Image 7: Image showing tomatoes planted in field

Source: (Author, 2019)

Image 8: Image showing tomatoes in tunnel

Source: Author (2019)

Tomatoes planted in the small-scale, low-cost system are greener and healthier in appearance therefore showing more potential for the market than the tomatoe plant in image 7. This evident that aquaponics, albeit highly dependent on water, in the long run it is more climate resilient than conventional farming methods.

Figure 18 Figure showing comparison between tomatoes

Source: Author (2019)

Figure 18 above show a comparison of tomatoes that are sixteen weeks old. The tomatoes in the tunnel look more ready for harvest than those that were planted in the field. The fruit on the tomatoes in the tunnel are more in number than the fruit on the tomatoes planted outside. The tomatoes in the tunnel appear to be more financially viable than tomatoes in the field. This is because, one can sell more tomatoes in the tunnel than those in the field.

Recommended aquaponic method: media beds and DWC

Developing tomatoes in aquaponic units: Tomatoes are a superb summer fruiting vegetable to develop utilizing all techniques for aquaponics, albeit physical help is essential. Given the high supplement request of tomatoes, particularly potassium, the number of plants per unit ought to be arranged by the fish biomass, so as to maintain a strategic distance from supplement insufficiencies(Monsees et al., 2017). A higher nitrogen focus is ideal during right on time stages to support plants' vegetative development; nonetheless, potassium ought to be available from the blooming stage to support organic product settings and development. Developing conditions: Tomatoes incline toward warm temperatures with full sun exposure. Beneath 8–10°C the plants quit developing, and night temperatures of 13–14°C empower organic product set (Rahman, 2016). Temperatures above 40 °C cause flower bud removal and poor natural product setting.

There are two significant kinds of tomato plants: determinate (regular creation) and uncertain (non-stop creation of botanical branches). In the principal type, plants can be left to develop as brambles by leaving 3–4 principle branches and evacuating all the helper suckers to redirect supplements to natural products. Both determinate and vague assortments ought to be developed with a solitary stem (two fold in the event of high plant energy) by evacuating all the assistant suckers (Ottinger et al., 2016). Be that as it may, in determinate assortments, the apical tip of the single stem must be cut when the plant arrives at 7–8 floral branches all together to support fruiting. Tomato depend on underpins that can be either made of stakes (bramble plants) or bound to vertical plastic/nylon strings that are appended to iron wires pulled on a level plane over the plant units. Tomatoes have a moderate resistance to saltiness, which makes them appropriate for zones where unadulterated freshwater isn't accessible. Higher saltiness at fruiting stage improves nature of the items (Webster and Lim, 2006).

Planting guidelines: Set stakes or plant bolster structures before transplanting to avoid root harm. Transplant the seedlings into units 3–6weeks after germination at the point when the seedling is 10–15cm and when evening time temperatures are continually above 10°C. In transplanting the seedlings, stay away from waterlogged conditions around the plant neckline to diminish any dangers of illnesses (Variyar et al., 2016). When the tomato plants are about 60cm tall, start to decide the developing technique (shrub or single stem) by pruning the pointless upper branches. Expel the leaves from the base 30cm of the fundamental stem to support a superior air flow and lessen contagious occurrence. Prune all the assistant suckers to support natural product development. Evacuate the leaves covering each organic product branch soon before aging to support nourishment stream to the foods grown from the ground quicken development. Reaping: For best flavor, collect tomatoes when they are firm and completely hued. Organic products will keep on maturing whenever picked half ready and brought inside. Natural products can be effectively kept up for 2–4weeks at 5–7°C under 85–90percent relative dampness (Sumberg et al., 2012) .

4.7.3. Cabbage

pH: 6–7.2

Plant dividing: 60–80cm (4–8 plants/m2)

Germination time and temperature: 4–7days; 8–29°C

Growth time: 45–70days from transplanting (contingent upon assortments and season)

Perfect temperature: 15–20°C (development stops at >25°C)

Light exposure: full sun

Plant height and width: 30–60cm; 30–60cm

Suggested aquaponic technique: media beds (Silveira et al., 2016).

Developing cabbage in aquaponic units: Cabbage is a profoundly nutritious winter crop. The plants develop best in media beds since they arrive at noteworthy measurements at gather and might be excessively huge and substantial for pontoons or develop channels. Cabbage is a supplement requesting plant, which makes it unacceptable for recently settled units (under four months old) (Somerville et al., 2014). In any case, attributable to the enormous space required, cabbage harvests take up less supplements per square meter than other winter verdant vegetables (lettuce, spinach, rocket, and so on.). Despite the fact that cabbage can endure temperatures as low as 5°C, the low temperatures may not be reasonable for refined fish.

Growing conditions: Cabbage is a winter crop with perfect developing temperatures of 15–20 °C; Cabbage develops best when the heads develop in cooler temperatures, so plan to gather before daytime temperatures arrive at 23–25°C (Nozzi et al., 2018). High groupings of phosphorus and potassium are fundamental when the heads start to develop. Combination with natural manures conveyed either on leaves or substrates might be fundamental in request to supply plants with sufficient degrees of supplements.

Developing directions: Transplant seedlings at 4–6 leaves and a tallness of 15 cm.

Position seedlings with an ideal planting thickness as per the picked assortment. In the occasion of day temperatures >25°C, utilize a concealing net of 20percent light concealing to keep the plant from catapulting (developing to deliver seeds) (Nozzi et al., 2018). Given the high occurrence of cabbage worms and different nuisances, for example, aphids, root slimy parasites and cabbage loopers, it is essential to do cautious checking and utilize natural (aquaponic safe) pesticides at the point when essential (Sunny et al., 2019).

Harvesting: Start reaping when cabbage heads are uncompromising with a distance across of about 10–15 cm (contingent upon assortment developed). Cut the head from the stem with a sharp blade, and spot the external leaves into the fertilizer canister. In the event that cabbage heads will in general break, it shows they are over-ready and ought to have been collected before (Webster and Lim, 2006).

4.7.4. Parsley

pH: 6–7

Plant separating: 15–30cm (10–15 plants/m2)

Germination time and temperature: 8–10days; 20–25°C

Development time: 20–30days after transplant

Temperature: 15–25°C

Light exposure: full sun; fractional shade at >25°C

Plant height and width: 30–60cm; 30–40cm

Suggested aquaponics strategy: media beds, NFT and DWC (Zou et al., 2016)

Developing parsley in aquaponics units: Parsley is a typical herb developed in both household what's more, business aquaponics units attributable to its healthful substance (plentiful in nutrients An and C, calcium and iron) and its high market esteem (Oladimeji et al., 2018). Parsley is a simple herb to develop as the supplement prerequisites are generally low contrasted and different vegetables.

Growing conditions: Parsley is a biennial herb be that as it may, it is customarily developed as a yearly; most assortments will develop over a two-year time span if the winter season is gentle with insignificant to direct ice. In spite of the fact that the plant can oppose temperatures of 0°C, the base temperature for development is 8°C. In the principal year, the plants produce leaves while in the second the plants will start sending up rose stalks for seed creation (Monsees et al., 2017). Parsley appreciates full sun for up to eight hours every day. Incomplete concealing is required for temperatures >25°C.

Growing guidelines: The fundamental trouble when developing parsley is the underlying germination, which can take 2–5 weeks, contingent upon how new the seeds are. To quicken germination, seeds can be absorbed warm water (20–23°C) for 24–48hours to mollify the seed husks (Diver and Rinehart, 2000). A short time later, channel the water and sow the seeds into spreads plate. Rising seedlings will resemble grass, with two thin seed leaves inverse one another. After 5–6weeks, transplant the seedlings into the aquaponic unit during late-winter. Reaping: Harvesting starts once the individual stalks of the plant are in any event 15cm long. Reap the external stems from the plant first as this will empower development all through the season. In the event that solitary the top leaves are cut, the stalks will remain and the plant will be less profitable. Parsley dries and stops well. Whenever dried, plants can be squashed by hand and put away in a water/air proof holder (Webster and Lim, 2006)

4.7.6. Basil

Image 9: Image showing Basil at harvesting stage

Source: Author (2019)

pH: 6–7

Plant separating: 15–30cm (10–15 plants/m2)

Germination time and temperature: 8–10days; 20–25°C

Development time: 20–30days after transplant

Temperature: 15–25°C

Light exposure: full sun; fractional shade at >25°C

Plant height and width: 30–60cm; 30–40cm

Suggested aquaponics strategy: media beds, NFT and DWC

Growing: Basil was one of the herbs that did very well in the small-scale, low-cost aquaponics system. The growing conditions were optimal for this herb and as a result it thrived.

4.8. Companion planting

Companion planting is a small-scale intercropping method that is very common in organic and biodynamic horticulture. The justifying theory is that the association of different plants has either a mechanical, repellent or dissuasive effect against pests (Finch et al., 2003). In addition, some beneficial effects on the complex soil/plant agro-ecosystem can be encouraged by the release of substances or root exudates from beneficial plants. Although some degree of pest control has been scientifically verified, the degree of success depends on: the level of pest infestation, the crop density, the ratio between crops and beneficial plants, and the specific planting times. Companion planting can be used in combination with other strategies within an integrated plant and pest management to obtain healthier crops in aquaponic systems (Held et al., 2003).

The list below (4.8.1.) gives a general overview of possible combinations according to biodynamic principles. Specific information can be obtained easily from the detailed literature available on organic and biodynamic agriculture.

4.8.1. Crop Companions: Incompatible

As mentioned before, it is important for aquaponics farmers to know the crops which are best suited to be planted together. These are referred to as crop companions. The following are crop companions which are incompatible, in other words, it is recommended that they not be planted together in the same cycle.

- Asparagus Tomato, parsley, basil
- Beans Most vegetables and herbs
- Beans, bush Irish potato, cucumber, corn, strawberry, celery, summer savory Onion Beans, pole Corn, summer savoury, radish Onion, beets, kohlrabi, sunflower
- Cabbage family (cauliflower, broccoli)
- Aromatic herbs, celery, beets, onion family, camomile, spinach, chard Dill, strawberries, pole

4.8.2. Crop Companions: Compatible

- beans, tomato
- Carrots English pea, lettuce, rosemary, onion family, sage, tomato Dill

- Celery Onion and cabbage families, tomato, bush beans, nasturtium –
- Corn Irish potato, beans, English pea, pumpkin, cucumber, squash Tomato
- Cucumber Beans, corn, English pea, sunflowers, radish Irish potato, aromatic herbs
- Eggplant Beans, marigold –_
- Lettuce Carrot, radish, strawberry, cucumber –_
- Onion family Beets, carrot, lettuce, cabbage family, summer savoury Beans, English pea
- Parsley Tomato, asparagus –_
- Pea, English Carrots, radish, turnip, cucumber, corn, beans Onion family, potato
- Radish English pea, nasturtium, lettuce, cucumber Hyssop
- Spinach Strawberry, fava bean
- Squash Nasturtium, corn, marigold Potato
- Tomato Onion family, nasturtium, marigold, asparagus, carrot, parsley, cucumber, basil Potato, fennel, cabbage family Turnip English pea Potato (Somerville et al., 2014)

CHAPTER FIVE: PRESENTATION AND DISCUSSION OF THE RESULTS

5.1. Introduction

This chapter presents and discusses the key findings of the studies. The discussion will draw on themes from the literature base of the study and the relationship between the findings and the existing literature. The methods of analysis that will be used in this chapter include descriptive and regression methods. The synthesis of the key findings are briefly explained in accordance with the objectives of the study. Concluding this chapter, the challenges experienced during the study are addressed, taking into consideration the knowledge gap that exists regarding low-cost, small-scale aquaponics systems.

When assessing the viability of aquaponics in low-cost systems, the question is not simply whether or not it is viable, but to what extent it is viable, and where and to whom would it be most applicable. This is because the viability can certainly be achieved, but the extent to which aquaponics can be maintained as a sustainable practice and how that practice can most efficiently be implemented is important (Love et al., 2015b). Thus, the viability assessment is implicit in how the practice could most effectively function. Consequently, considerations from this chapter manage a variety of factors, drawing from the previous chapters into a synthesized picture of aquaponics that looks at ideal points of entry for a business through demographics, market characteristics, returns on investment and energy costs, previous case studies, policy and limitations and extended research opportunities (Rizal et al., 2018).

5.2. Consumer attitude

From the previous chapters, several considerations become apparent. To begin, consumer attitudes and behaviours are conditioned on a myriad of factors, and they need to sustain a connection to the products in to provide a stronger willingness to purchase products. With organics, there is a drive for health promotions, along with quality and environmental efficacy (Short et al., 2017). Forging a relationship with the producer helps to increase credibility, which needs to be bolstered by the facility’s narrative.

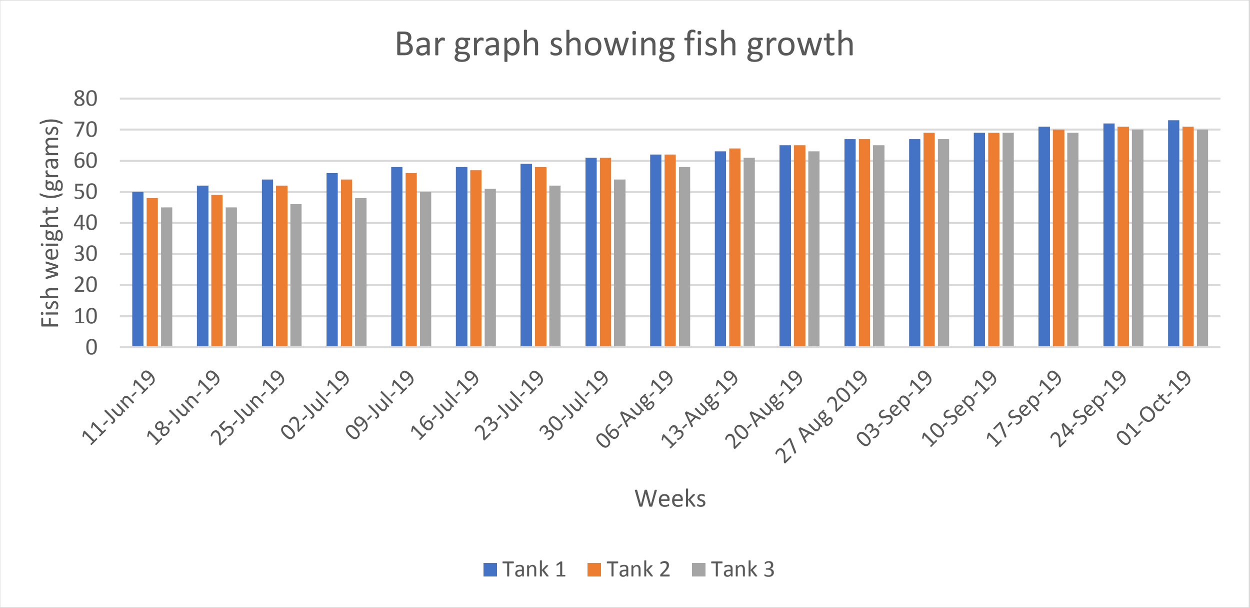
Consumers need to take on a position where they feel their input can help dictate the product selection and characteristics. The country depends on imports, of which several varieties are not necessarily adept to the environment, even with increased greenhouse focus. For the products that are viable, an increase in production must either outweigh the current prices or provide a fitting incentive to purchase produce with high premiums (Short et al., 2017). According to research (Verbeke et al., 2007), the economic potential of aquaponic systems looks promising based on the studies at their system in the UVI. They warn, however, that it would be inaccurate to make sweeping statements about the economic potential because many aspects of an aquaponics system vary by location

5.3. Objective One

- To determine the biomass production of fish from a small-scale, low-cost aquaponic system.

Below is a bar graph showing the fish growth patterns in the small-scale, low-cost aquaponic system in Ndwedwe.

Figure 19: Bar graph showing fish growth



Source: Author (2019)

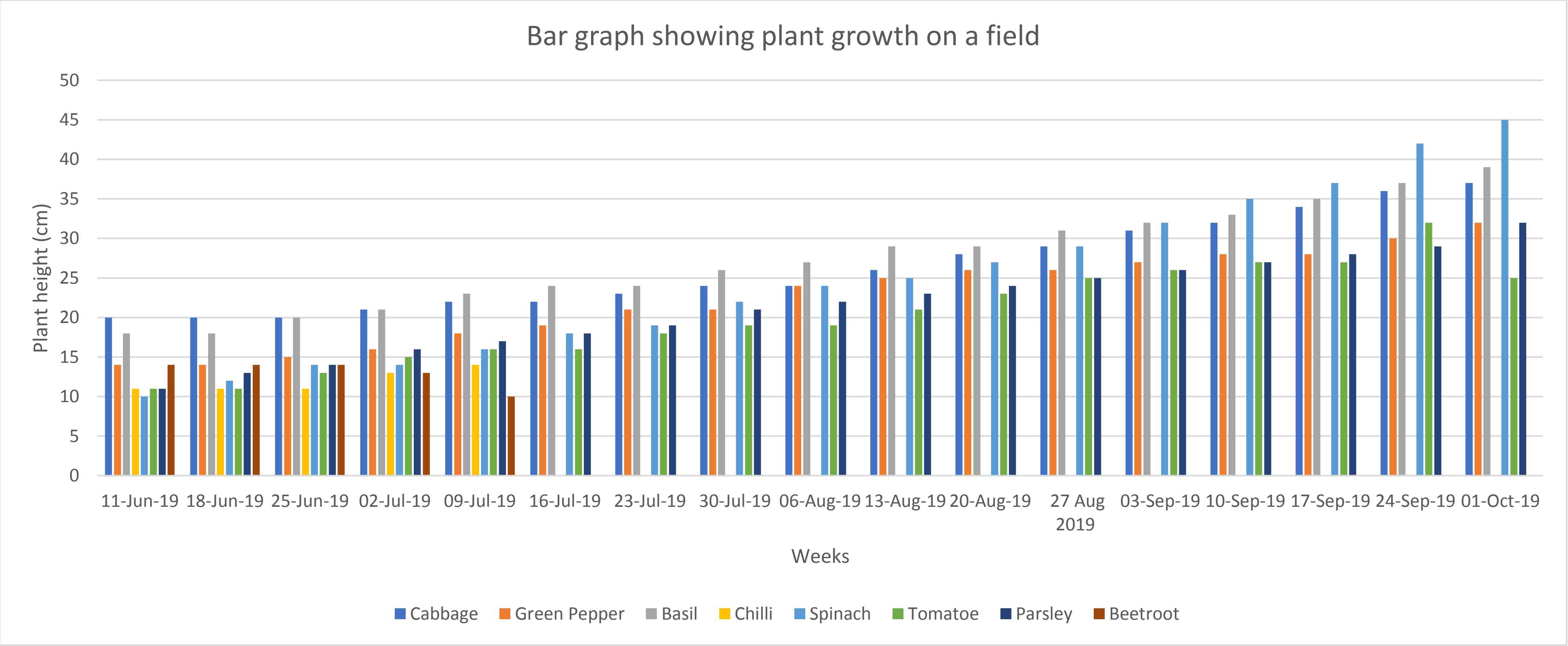
The fish that were added to the system came to 300 fish, 100 added to each tank. The bar graph indicates that the fish grew, albeit not at the rate which was expected. The slow fish growth can be attributed to multiple factors namely; temperature, pH and feed conversion ratio. One of the main challenges of the study was not just the issue of drought in Ndwedwe but also raising the temperature to be at a favourable level in the three fish tanks.

5.4. Objective Two

- To determine the biomass production of plants from a low-cost aquaponic system.

Four weeks after planting, the plants showed a nutrient deficiency. They were yellow and brownish in appearance. There were numerous possibilities as to why the plants were showing a nutrient deficiency.

Figure 20: Bar graph showing biomass growth in field

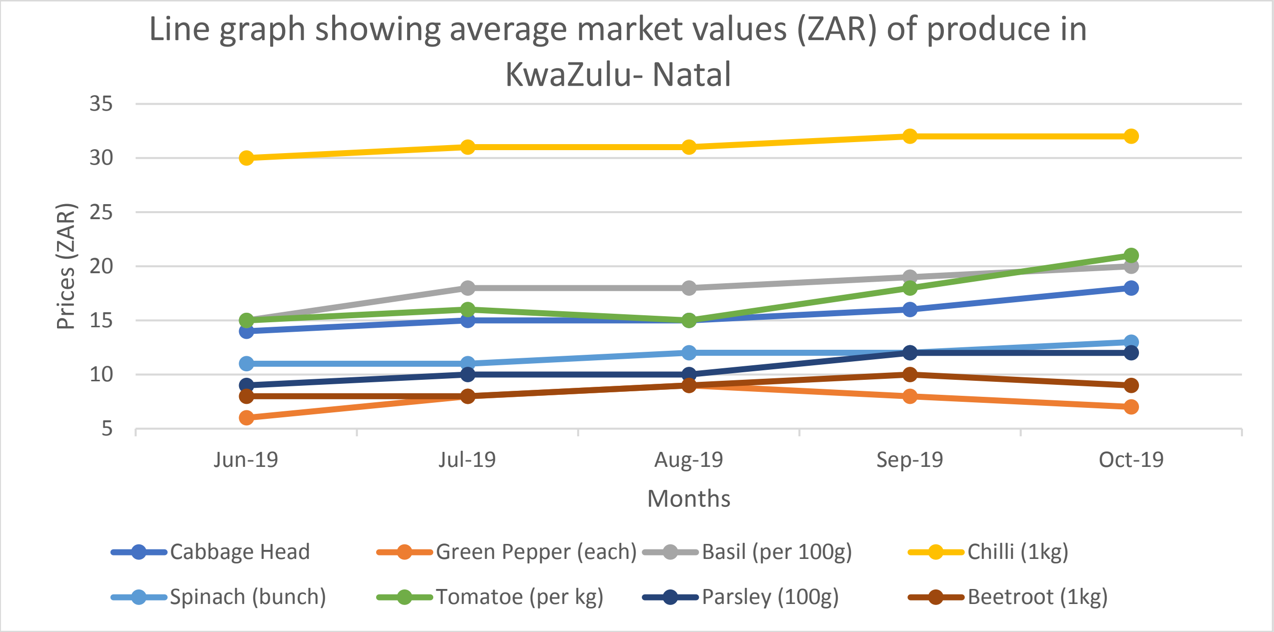


Source: (Author, 2019)

5.5. Objective Three

- To determine the financial viability of the biomass produced in a low-cost aquaponic system.

Figure 21: Line graph showing average market values of biomass



Source: (Author, 2019)

The graph above shows the market values of the plant biomass that was planted in the small-scale, low-cost aquaponics system in Ndwedwe. The line graph would be useful to a small-scale farmer (and commercial) looking to sell his biomass output to locals.

5.6. Objective Four

- To determine the factors that affect financial viability in a small-scale, low-cost aquaponics system.

Low-Cost

The definition is derived from the FAO Small-scale aquaponics food production technical paper (2014) (Somerville et al., 2014)

A low-cost aquaponics system is low-tech using low-cost locally available materials. The aquaponics system is closed-loop with a maximum of 30m2 for the growing area. The production of fish and plants within a small area allows small scale farmers to achieve the daily income target of USD1.25 and food and nutrition security set by the sustainable development goals 2030.

Image 10: Image showing biomass growth in tunnel

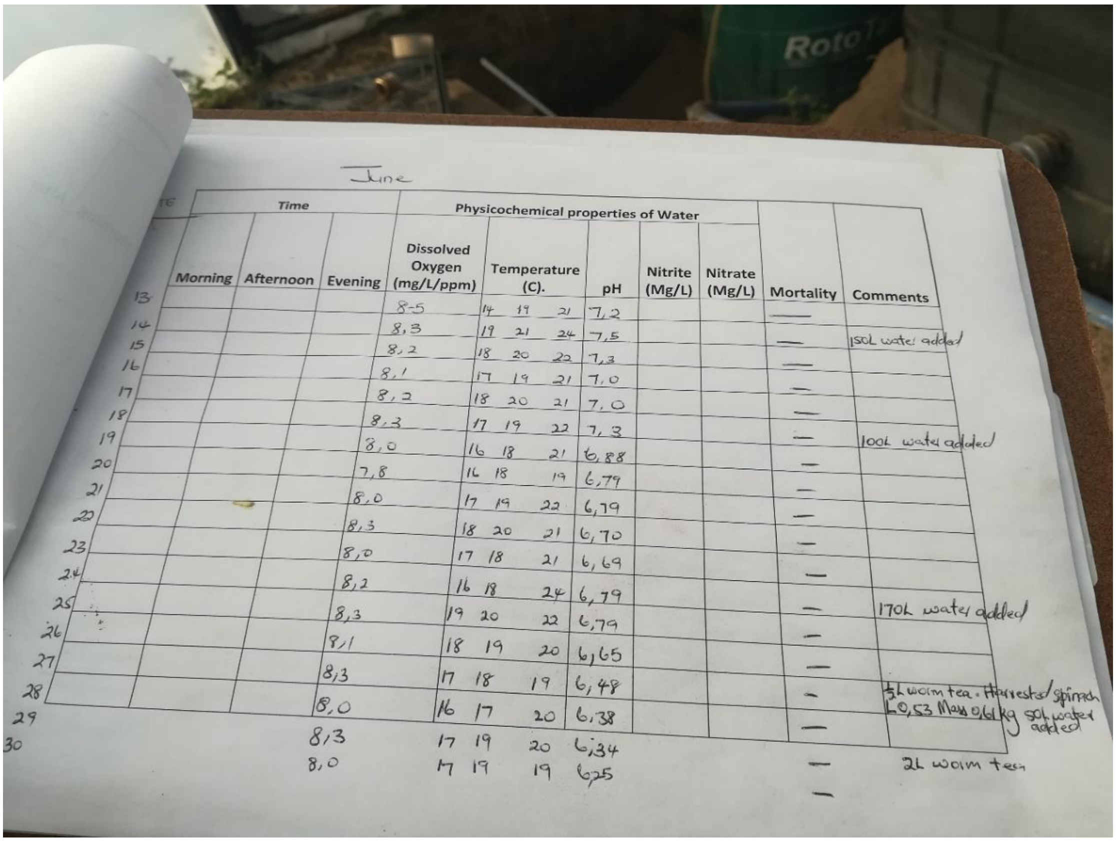
Source: Author, 2019

Two South African authors have also commented on the financial viability of aquaponics in South Africa. They claim that the systems described in their manuals are economically feasible, granted that the correct management practises are maintained (Lapere, 2010). These statements do not correspond with the research done in this thesis. Rather, the income figures they quote are overly optimistic, and various costs are overlooked.

5.7. Guidelines for successful aquaponics practice

- Monitoring and management of the system daily.
- Ensuring of water and air circulation in the system.
- Consistent maintenance and monitoring of water quality.
- Choosing fish and plants that are suitable for the environment in which the system is set up.
- It is imperative to not over stock the fish tanks, recommended stocking density is 20 kg/1000 liters).
- Algae and any other impurities should be removed from the tanks as this can complicate the nitrification process.
- Harvesting and restocking should be spaced out accordingly in order to ensure a healthy aquaponics system. (Proksch et al., 2019).

Image 11: Image showing farmer's daily log



June

TE	Time			Physicochemical properties of Water						
	Morning	Afternoon	Evening	Dissolved Oxygen (mg/L/ppm)	Temperature (C).	pH	Nitrite (Mg/L)	Nitrate (Mg/L)	Mortality	Comments
13				8-5	14 19 21	7,2			—	
14				8,3	19 21 24	7,5			—	150L water added
15				8,2	18 20 22	7,3			—	
16				8,1	17 19 21	7,0			—	
17				8,2	18 20 21	7,0			—	
18				8,3	17 19 22	7,3			—	
19				8,0	16 18 21	6,88			—	100L water added
20				7,8	16 18 19	6,79			—	
21				8,0	17 19 22	6,79			—	
22				8,3	18 20 21	6,70			—	
23				8,0	17 18 21	6,69			—	
24				8,2	16 18 24	6,79			—	
25				8,3	19 20 22	6,79			—	170L water added
26				8,1	18 19 20	6,65			—	
27				8,3	17 18 19	6,48			—	½L worm tea. Harvested spinach L0,53 Mass 0,61kg 50L water added
28				8,0	16 17 20	6,38			—	
29				8,3	17 19 20	6,34			—	
30				8,0	17 19 19	6,25			—	2L worm tea

Source: Author, 2019

5.8. Challenges of the study

This section will address the various challenges which were experienced during the course of the study. These challenges included; pH, temperature, nutrient deficiency, drought and overcrowding.

5.8.1. pH

Aquaponics is quite a sophisticated medium of growing food. This is due to two enterprises being merged; the fish and plant component. The fish and plant component have a symbiotic relationship in the sense that, when one component is out of balance, it will affect the other (Zou et al., 2016). During the early stages of the study (June 2019 to July 2019), the fish component experienced some challenges with pH. At first, it was not clear what was causing the high pH levels but after some extensive research and reading on pH in aquaponics, literature revealed that an increase in pH can be accrued to:

5.8.2. Over feeding fish

Fish feed consists of fishmeal, vegetable proteins and binding agents like wheat. Water is added to form a paste which is then pressed through metal holes to form pellets which are then dried up. The listed ingredients may not have a naturally high pH level but the fish were not consuming the feed at an acceptable rate to avoid the pH increasing. Mr Ngcobo, who stewards the aquaponics system was initially feeding the fish 3 grams of feed in all 3 tanks twice a day, In the morning at 9am and in the evening at 6pm. He then reduced the feed to 1.5 grams once a day. Uneaten nourishment waste ought to never be left in the aquaponics framework. Feed squander from overloading is devoured by heterotrophic microbes, which expend generous measures of oxygen. In expansion, breaking down nourishment can expand the measure of smelling salts and nitrite to dangerous levels in a moderately brief period. At last, the uneaten pellets can stop up the mechanical channels, prompting diminished water stream and anoxic regions. As a rule, fish eat all they have to eat in a 30minute period. After this timeframe, expel any nourishment. In the event that uneaten nourishment is discovered, bring down the measure of feed given whenever (Tyson and Simonne, 2014).

5.8.3. Poor filtration

Another factor that increased the pH was insufficient filtration in the system, ultimately resulting in poor water quality. The early stages of the planting period (June to July 2019) were experimental as there was minimal information on how to set up and maintain a small-scale, low-cost aquaponics system. The issue of poor filtration was addressed by converting one of the deep water culture planting areas into a gravel bed to improve filtration in the system. This decision was informed by the overall appearance and health of the plants. The plants which were in the gravel beds were thriving as compared to those which were in the deep water culture. This confirmed what (Buzby and Lin, 2014) suggested on using gravel beds in a small-scale system as the gravel acts as a medium that assists nutrient breakdown in the system and ultimately improves the overall conditions of both the fish and plants.

Image 12: Image of pH buffer

Source: (Author, 2019)

Above is a pH balancing product for any agricultural activities. It is called, “pH UP”. The product is a highly concentrated combination of BASE nutrients, the instructions recommended three lids per 1000 litres. Altogether, nine lids of pH up were added to the fish tanks. Each tank was 1000 litres.

It is indispensable for good plant development to keep up the pH somewhere in the range of 6 and 7, so plants approach all the supplements accessible in the water. Include limited quantities of base or cradle at whatever point the pH approaches 6.0 so as to keep up ideal pH levels. Include water or right with corrosive any alkalinity-rich water just if the hardness level in the aquaponics framework is too high to even consider preventing nitrifying microscopic organisms from normally bringing down the pH to ideal levels (Tacon and Metian, 2013). Treat the water with corrosive outside the aquaponics framework, and empty the water into the framework in the wake of checking the pH.

Before: pH above 8

Image 13: Image of water quality before pH buffer

Source: Author (2019)

The image above shows the poor water quality when the pH had gone above 5. The water was murky and brown in colour. This was mostly due to the overfeeding of the fish and the poor filtration of the small-scale aquaponics system. The overfeeding and the poor filtration resulted in the pH spiking therefore putting the system at risk of failing and threatening the fish mortality

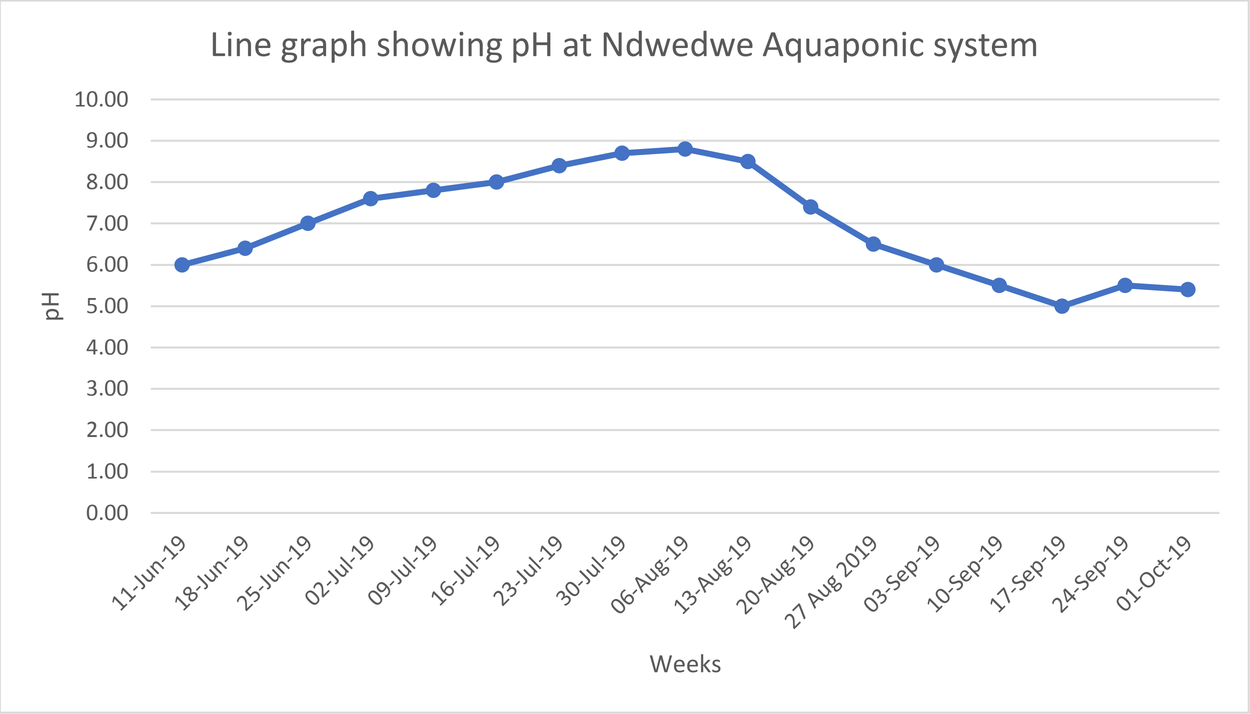
After: pH below 7

Image 14: Image showing water quality post pH buffer

Source: (Author, 2019)

There was certainly an improvement in the system after flushing the system, adding pH up and improving filtration. This is evidence that aquaponics, albeit in a small-scale, low-cost system can be a complex operation that requires scientific expertise to solve some of the challenges the system can potentially face. Below is a line graph depicting the pH patterns of the system during the course of planting to harvesting:

Figure 22: Line graph showing pH levels



Source: Author (2019)

As mentioned prior, pH is the measure of acidity or alkalinity of a solution on which neutrality is the value of 7 on a pH scale (Zou et al., 2016). The line graph above depicts the pH patterns of the small-scale, low-cost aquaponics system in Ndwedwe. The pH was above 5 at the beginning of the study, however the system was not stocked with 300 tilapia yet therefore there was less fish waste and less feeding taking place. For about three weeks the pH spiked due to overfeeding the fish by feeding them three times a day instead of feeding them 5grams of fish feed once a day.

Relationship between pH and financial viability

There are multiple factors that affect financial viability including variables that may not necessarily be a direct factor but may be a secondary factor. pH is a secondary factor that affects financial viability because, pH affects water quality in an aquaponics system and the water quality is vital to ensuring that the biomass produced in the aquaponics system is of good quality and yields a profitable harvest. Therefore, managing the pH in any aquaponics system is imperative because, it determines whether the harvest is a success or a total loss.

In a small-scale, low-cost system the loss may not be as great as in a commercial aquaponics system because of the scale and the type of biomass that is in the system however, negligence of pH management can be detrimental to any aquaponics system and result in a total loss of funds. The financial viability of aquaponics is highly dependent on managing the pH in the system and this study proved that without close monitoring and management of pH, the system can threaten to completely fail making it non-financially viable.

5.8.4. Temperature control

In aquaponics practice temperature control is among the main variables that determine whether the system succeeds or not. Albeit, this study was not focusing on the implications of temperature in a low-cost, small-scale aquaponic system, it was impossible to overlook the temperature variable and its possible implications on the financial viability of the biomass produced in a small-scale, low-cost aquaponic system. Aquaponics relies heavily on optimum temperatures to succeed and be stable (Andrews, 2018). Depending on the type of fish in the system and the plant biomass, the optimum temperatures vary, however, aquaponics always requires warmer temperatures to be a success. This study specifically focused on the financial viability of the biomass produced in a small-scale, low-cost aquaponic system. However, temperature was a problematic variable as it resulted in the very slow growth of the tilapia which were in the aquaponic system.

Red breast tilapia are the fish which were stocked in the system. Fish in general are temperature sensitive species, although, some fish species are more tolerant to cooler temperatures than others. As mentioned before, red breast tilapia is a fish species that is suited to warmer temperatures ranging from 24 to 30 degrees (Hunter et al., 2017). Temperatures lower that 26 compromise the fish growth and overall fish size. The challenge was in increasing the water temperature in the fish tanks. (Ru et al., 2017) suggests that increasing the air temperature in a tunnel which an aquaponics system is situated, results in the water temperature increasing. During the course of this study, the air temperature in the tunnel which the small-scale aquaponics system was placed was above 25 degrees most days, however there was a real challenge with increasing the water temperature as it remained between the 15 to 20 degrees range most days.

Relationship between temperature and financial viability

The temperature variable in the study may be a secondary component that affects

5.8.5. Nutrient Deficiency

Image 18 below shows tomatoes that are three weeks old. The tomatoes were planted using the deep water culture method.

Image 15: Image showing nutrient deficiency in tunnel

Source: Author (2019)

The plant biomass that was planted in the DWC showed signs of nutrient deficiency, especially the tomatoes. This can be attributed to the pH challenge that took place concurrently the nutrient deficiency manifested in the DWC. Another important factor was that there was no pre-research done prior to the inception of the study on the plant biomass that is suited to DWC and gravel beds.

5.8.6. Water shortage: Drought

The location of the study was Ndwedwe which is situated in the North of KwaZulu Natal, 957m above sea level. This community was experiencing severe drought during the course of conducting this study and as a result the plants which were planted on the field about twenty metres away from the tunnel where the small-scale, low-cost system is based. Below is an image of plants that did not survive the drought that were planted concurrently as those that were planted in the small-scale, low-cost aquaponics system.

Image 16: Image showing drought in field

Source: Author (2019)

5.8.7. Overcrowding/ foliage

Foliage can pose a threat to the plant biomass in an aquaponics system. The small-scale aquaponics systems Ndwedwe struggled to contain the foliage as it was small scale and the plants that were planted in it were foliage rich plants; tomatoes, peppers and cabbage. The image below shows the small-scale system overcrowded with foliage. Overcrowding can reduced the quality of the plant biomass as this creates competition for light amongst the plants and some do not get exposure to light and as a result have stunted growth or they die.

Image 17: Image showing foliage in tunnel

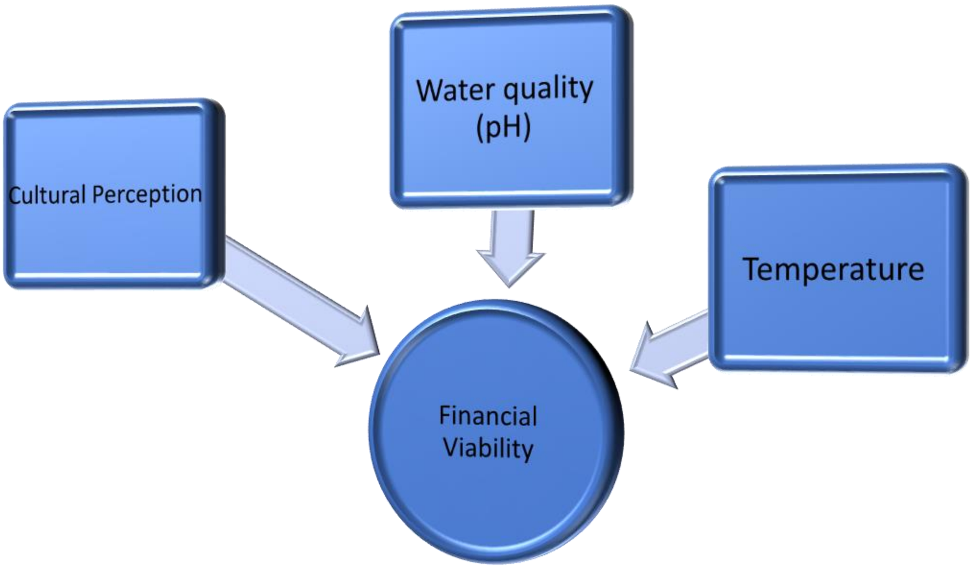
Source: (Author, 2019)

6. Factors affecting financial viability

Figure 22 shows the factors drawn from the study that proved to affect the financial viability of biomass produced in a small-scale, low-cost aquaponics system. During the course of the study, it was evident that the pH affected the water quality which would have eventually affected the biomass output of the system. If pH and water quality is not monitored closely, it can result in the collapse of the system making it non-financially viable. Temperature was also another component that certainly made the fish biomass non-financially viable as the red breast tilapia did not grow to their optimum size and weight due to the temperatures being too low. On a commercial scale, it would not be financially viable to set up an aquaponics system in Ndwedwe as temperatures are not optimal for most fish including red breast tilapia.

In any study or marketing strategy, the consumer perception of a product can be the gap between the success or failure of the product. Albeit, a consumer perception study was not conducted but it a factor that certainly affects whether aquaponics will be financially viable or not (Short et al., 2017)

Figure 23: Diagram showing variables affecting financial viability in aquaponics



Source: Author (2019)

7. Summary of discussion

Table 3: Summary of discussion

Objectives	Result	Discussion
1. To determine the biomass production of fish from a small-scale, low-cost aquaponic system.	Fish were struggling to grow, therefore could not be harvested at the end of the seventeen-week period because they were too small even though they were fed daily.	Temperature was the main challenge in growing the fish to optimum size hence, climate plays a vital role in determining financial viability of fish in a small-scale, low-cost aquaponic system.
2. To determine the biomass production of plants from a small-scale, low-cost aquaponic system.	Plant biomass in gravel beds grew better than plant biomass in DWC. This can be alluded to poor filtration in the DWC and the plant choice in the various grow mediums.	The plants in the DWC had nutrient deficiency, they were yellow in appearance and stunted in growth. Whereas, plants in the gravel beds were thriving. This may be due to the lack of research done before the study to determine which plants thrive in which grow medium.

3. To determine the financial viability of the biomass produced in a small-scale, low-cost aquaponic system.	The biomass produced in a small-scale, low-cost aquaponic system is financially viable, provided the water input is harvested from the rain.	Financial viability of biomass is imperative to aquaponics, especially for small-scale farmers who are looking to commercialise because, it will assist with pricing in such a way that the small-scale farmer does not make a loss.
4. To determine factors affecting financial viability in a small-scale, low-cost aquaponic system.	There is a relationship between the financial viability of biomass produced in a small-scale, low-cost aquaponic system and the following; pH, temperature, consumer perception.	Financial viability analysis is critical in aquaponics as aquaponics is a complex and expensive set up, therefore if it is not financially viable, it is not worthwile.

Source: (Author, 2019)

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

This chapter is the synthesis of the whole study. The key findings, recommendations and conclusions of the study will be reiterated and the necessary recommendations for future studies related to low-cost, small scale aquaponics systems will be made. This chapter will also briefly explain the implications this study will have on all spheres of development; society, the environment and economics.

Aquaponics is a symbiotic, closed-loop system whereby both fish and plants exchange nutrients and grow in the process. As much as aquaponics is a sustainable practice it is also complex and requires a holistic approach in terms of its financial viability and biomass production.

6.2. Implications of this research

The implications of a study are the impacts the study will have, whether negative or positive. There are more positive implications of this study then there are negative. The implications that a study has have the potential to inform decision-making processes for future developments and studies. This particular study impact prospective aquaponics farmers the most as it focuses on the financial viability of the biomass produced in a small-scale, low-cost aquaponics system. Without knowing whether the biomass produced in a small-scale, low-cost aquaponics system is financially viable or not, farmers are at risk of making uninformed decisions of setting up a small-scale, low-cost system only to fail and make a loss (Forchino et al., 2018). This study is particularly important because it was conducted in Ndwedwe, a rural community ridden by drought. The weather conditions in this community are not favourable to agricultural activities but aquaponics proved to be an adaptation method to the harsh climate conditions.

Below is a summary of the positive implications this study has on all spheres of development; social, environmental and economic.

6.2.1. Significant advantages of aquaponics food farming:

This section will summarise the key advantages of aquaponics which have been covered in the study.

6.2.2. Water efficient

Water use in hydroponics and aquaponics is a lot of lower than in conventional farming methods. Water is lost from in-ground farming through dissipation from the surface, transpiration through the leaves, and permeation into the subsoil. Be that as it may, in soil-less culture, the main water use is through harvest development and transpiration through the leaves (Rockström et al., 2010). The water utilized is without a doubt the base expected to develop the plants, and just an irrelevant measure of water is lost for dissipation from the dirt less media. In general, aquaponics utilizes just about 10percent of the water expected to develop the equivalent plant in soil. Consequently, soil-less development can possibly permit generation where water is rare or costly.

6.2.3. Soilless

Due to the fact that soil is not required, soil-less culture techniques can be utilized in territories with non-arable land. One normal spot for aquaponics is in urban and peri-urban territories that can't bolster customary soil farming. Aquaponics can be utilized on the ground floor, in storm cellars (utilizing develop lights) or on housetops. Urban-based horticulture can likewise lessen the carbon footprint since transport needs are extraordinarily reduced (Ru et al., 2017). Another significant application for aquaponics is in different zones where conventional farming can't be utilized, for example, in regions that are incredibly dry (e.g.-deserts and other parched atmospheres), where the dirt has high saltiness (for example costal and estuarine zones or coral sand islands), where the dirt quality has been corrupted through over-utilization of manures or lost in view of disintegration or mining, or by and large where arable land is inaccessible inferable from residency, buy expenses and land rights (Þórarinsdóttir et al., 2015). All around, the arable land appropriate for cultivating is diminishing, and aquaponics is one technique that permits individuals to seriously develop nourishment where in-ground agribusiness is troublesome or incomprehensible.

6.2.4. Does not utilize composts or synthetic pesticides.

Synthetic compost and pesticides have a level of toxicity to them, albeit they are used in the majority of agricultural practices. Aquaponics, however, uses fish waste as compost in a recirculatory system. In cases where there are pest invasions, apple cider and bicarbonate of soda are usually used to ward off pests.

6.2.5. Higher yields and subjective creation

The most serious hydroponic culture can accomplish 20–25percent more significant returns than the most serious soil-based culture, albeit adjusted down information by hydroponic specialists guarantee efficiency 2–5 times higher (Villamar, 2018). This is when hydroponic culture employments comprehensive nursery the board, including costly contributions to clean and treat the plants. Indeed, even without the costly information sources, the aquaponic systems portrayed in this distribution can rise to hydroponic yields and be more gainful than soil. The fundamental explanation is the way that dirt less culture enables the rancher to screen, keep up and alter the developing conditions for the plants, guaranteeing ideal constant supplement balances, water conveyance, pH and temperature. Furthermore, in soil-less culture, there is no challenge with weeds and plant profit by higher control of bugs and sicknesses (Smith et al., 2017).

6.2.6. Organic administration and creation.

Creepy crawly nuisances are risky for plant generation since they convey maladies that plants can contract. Bugs additionally remove fluids as they drill into plant tissues, driving to hindered development. Controlled conditions, for example, nurseries, can be especially risky for bugs on the grounds that the encased space gives ideal conditions to creepy crawlies without rain or wind (Rafiee and Saad, 2005). Irritation the board for outside conditions additionally varies from that in secured development (net houses, nurseries), due to the physical partition of the plants from the encompassing zone, which permits the utilization of helpful creepy crawlies indoor to execute/control the bug bothers. Creepy crawly bother predominance is additionally exceptionally reliant on atmosphere and condition. Irritation the executives in mild or parched zones is simpler than in tropical districts, where higher rate and rivalry among bugs make bug control an unmistakably increasingly troublesome errand. As aquaponic units keep up an autonomous biological system, it is typical for a large group of smaller scale creatures and little bugs and insects to exist inside the media beds. Be that as it may, other hurtful creepy crawly bugs, for example, whiteflies, thrips, aphids, leaf diggers, cabbage moths furthermore, creepy crawly bugs feed upon and harm the plants. A typical practice for managing risky bug bothers in soil vegetable generation is to utilize substance pesticides or bug sprays, however this is unthinkable in aquaponics (Mercer et al., 2012). Any solid synthetic pesticide could be deadly for angle just as the gainful microorganisms living in framework. In this manner, business concoction pesticides should never be utilized. Be that as it may, there are other viable physical, ecological and social controls to decrease the danger of bugs from aquaponics. Bug sprays and obstacles ought to be viewed if all else fails. By the by, fruitful the executives incorporates crop and natural administration with the utilization of natural what's more, organic bug obstacles (Monsees et al., 2017).

Soil-less culture doesn't require furrowing, working, mulching or weeding. On huge ranches, this likens to bring down dependence on agribusiness apparatus and petroleum derivative utilization. In little scale agribusiness, this likens to a simpler, less work escalated practice for the rancher, particularly in light of the fact that most aquaponics units are raised off the ground, which stays away from stooping (Sayara et al., 2016) . Reaping is likewise a basic system contrasted and soil-based agribusiness, also, items don't require broad cleaning to evacuate soil sullying.

6.2.2. Cost Implications

It will cost more to develop biomass (fish and plants) independently than it will cost to develop it in a minimal effort, small-scale, low-cost aquaponics system. However, it is important to have a basic knowledge on water chemistry and companion planting prior to embarking on aquaponics farming, as this is essential to saving costs and making aquaponics a financially viable operation that can succeed.

6.2.3. Knowledge Gap

Aquaponics is largely being practiced at a commercial scale, therefore there is a knowledge gap in low-cost, small-scale aquaponics farming. This study honed in on the financial viability of the biomass produced in a low-cost aquaponics system. Albeit, the production will be less in a small-scale, low-cost aquaponics system, farmers will now be able to estimate the cost implications and benefits of various crops that are suitable for aquaponics.

6.3. Limitations of the study

This section of the study will briefly elaborate on the limitations that the study encountered which are imperative as they inform future studies.

6.3.1. Limited literature on low-cost

The literature base for the financial viability of biomass output in a low-cost aquaponic system is sparse and has not been explored as extensively as other strands of literature. However, this particular limitation presented an opportunity to explore and investigate unconventional, unexplored avenues of producing food at a low-cost using a low-cost system. The widespread literature is based on commercial aquaponic systems such as the UVI model (Goddek et al., 2015a) which is the model most studies have used to draw conclusions. Conducting a study on a low-cost, small scale model was a challenge but also an opportunity to address the knowledge gap on low-cost, small scale aquaponic systems.

Aquaponics framework plan and application can be viewed as a profoundly multidisciplinary approach drawing from natural, mechanical and structural building plan ideas just as sea-going and plant related science, organic chemistry, and biotechnology. Framework explicit estimations and control innovations additionally require information of subjects identified with the field of software engineering for programmed control frameworks (Shafahi and Woolston, 2014). This significant level of unpredictability fundamentally requests inside and out learning and mastery of every included field. The greatest test in business aquaponics is its multi-disciplinarity, requiring further skill in financial aspects, money and promoting. Hence, a high level of field-explicit understanding in terms of both reasonable and inside and out hypothetical information is required. This prompts an expanding level of intricacy, which straightforwardly influences the effectiveness elements of the running framework (Somerville et al., 2014). In light of a legitimate concern for most noteworthy effectiveness and efficiency, some numerical exchange offs are suggested and are illustrated beneath. They incorporate pH adjustment, supplement equalization, phosphorus, and nuisance the board.

6.3.2. Financial factors

One of the primary factors that decide the conceivable accomplishment of aquaponics is its climate resilience. The combination of both fish and plants pairs the dangers of the venture that, so as to be beneficial, must amplify both plant and fish generation and incomes. This suggests an examination on the potential markets is a basic advance towards the improvement of a marketable strategy, as it ought to reasonably discover all the potential items, recognize the net revenues and distinguish the key clients (Sunny et al., 2019).

6.3.3. Ecological factors

There are some key contemplations in figuring out where aquaponics is generally pertinent. Districts on the planet where soil ripeness is poor (and especially where recharging the dirt with supplements by means of natural material is troublesome as well as costly) what's more, water is rare are the perfect areas. Aquaponics is focused with even the most profitable conventional aquaculture and farming frameworks regarding water use (Suhl et al., 2016). Aquaponic nourishment creation is very water productive, as the vegetable developing techniques are soil-less. Be that as it may, to go up against hydroponics, fish–plant frameworks ought to be considered overall so as to legitimize higher establishment costs. When mulling over these elements, semi-parched areas with poor access to water would remain to profit the most from this new technique for nourishment creation. Water is a critical factor, particularly for quality measures. Aquaponics has the extraordinary preferred position of recycling water, which maintains a strategic distance from any need to acquire huge day by day volumes to make up for misfortunes. In zones where water is sloppy, debased by toxins or pathogens/parasites, aquaponics, just as RAS, is a perfect framework to enhance fish creation, lessen mortality of sea-going creatures and improve quality (Wongkiew et al., 2017). In this case, the additional ventures expected to supply little volumes of good-quality water (e.g.through downpour reap or artesian wells) can be effectively recouped by the additional worth from greater fish and lower death rates. Saltiness levels in water are the following stage in the water evaluation process. While freshwater fish can endure certain degrees of saltiness, increments in water electric conductivity (EC) over specific levels (for example 2000microSiemens) limits the development of salt-narrow minded vegetables (Silveira et al., 2016).

This would push rural farmers to think about just salt-tolerant species, with potential dangers of decreased benefits attributable to economic situations which may not be so open. Moreover, the development of supplements and saltiness through the seasons because of irregular characteristics between framework admission (feed) and plant take-up could similarly carry the aquaponic units to face expanded saltiness issues. These would should be explained through moderate water dumping or altered administration (constraint in feed use, trimming with salt-retaining plants) that may diminish frameworks' benefit or efficiency and may require a more elevated level of aptitude in administrators. Atmosphere is another main consideration, as it will decide the additional expense for every unit to keep up the perfect natural conditions for aquaponic nourishment creation. By and large, locales where the normal day by day air temperatures during the time are 20–30°C are the perfect for tropical fish, for example, tilapia, and warmth-tolerant plants (Mimura et al., 2015). In this way, the selections of harvests and fish essentially influence the expenses if climatic control is expected to coordinate the perfect developing states of the two parts. Also, locales where normal every day air temperatures are ideal, yet generally change during the day and night (for example good countries and bumpy areas), would be especially hazardous for fish generation. This is on the grounds that huge changes cause worry to the creatures. Consideration should likewise be paid to the seasons (Lapere, 2010). Cold winter seasons will compel aquaponic ranchers to either put resources into vitality requesting warming frameworks for their nurseries or stop generation totally for specific months. It is along these lines imperative to think about the creation arrangement cautiously and conceivably discover elective species that keep away from useless areas of the year.

Stretched out stormy seasons power ranchers to ensure their units with solid shelters or on the other hand nurseries, as enormous volumes of downpour could harm crops, prompt the frameworks to flood or to weaken too much the supplements in water. Be that as it may, if from one perspective this need requires additional ventures, on the other it tends to be productive in regions where conventional agribusiness is seriously restricted inferable from flooding or supplement overflow. The same arrangement additionally relates to twist, as the nearness of an ensured domain could bring more significant returns and better nature of vegetable items, while conventional agribusiness would battle. Summer seasons can cause water overheating (König et al., 2016). Despite the fact that strategies to keep temperatures generally low during hot periods are very straightforward and can be bolstered with appropriate framework structures, it is conceivable that water temperatures would ascend to imperfect levels during amazingly hot periods if no water-cooling frameworks were utilized. This would restrict ranchers' vegetable development and choice, despite the fact that it may not influence tropical fish or nitrifying microscopic organisms.

6.3.4. Summary of limitations of the study

- Aquaponics has an expensive start-up
- Knowledge of fish, microbes and plant generation is required for every farmer to be effective.
- Fish and plant types do not always work well combined.
- Optimal temperatures are key to both fish and plants.
- Aquaponics is mostly organic, therefore, chances of using synthetic supplements are reduced and this can delay balancing the nutrients in the system should there be a crisis.
- Aquaponics is complex and requires specialised skills
- Daily administration is compulsory.
- Although not excessive, aquaponics does require energy in order to function.
- Requires dependable access to power, fish fingerlings and plant seeds.

- Alone, aquaponics won't give a total eating routine (Somerville et al., 2014).
- Limited studies on low-cost, small-scale aquaponic systems

6.4. Recommendations to solve the research problem

The stocking densities, pond sizes, and area of aquaponics growth should be calculated scientifically, so that the space and resources are used efficiently. This is not always the case and some of farmers have received information from sources that do not use well-established or scientific information in order to base their recommendations upon. It is also recommended that farmers keep a record of all costs in order to ensure that they are keeping tabs on whether they are making a profit or loss. Without keeping records on the finances, one risks having a financially unviable operation resulting in failure.

6.5. Recommendations for future studies

This section will cover recommendations for future studies. This is imperative because, aquaponics will continue to be studied, therefore it is important that knowledge is shared so that future studies do not make the same errors perhaps that previous studies have made and also for the edification of the aquaponics body of knowledge that addresses small-scale, low-cost systems.

6.5.1. Supplementary Feeding

Fish can be beneficially provided with advantageous feeds that are locally accessible. The utilization of new feed would in reality give creatures strengthening proteins for their development. It can likewise give nutrients or minerals that may be lacking in the pellets (Rakocy et al., 2016). A wide scope of live feeds is available–the decision relies upon the fish refined and neighborhood accessibility. Be that as it may, it is imperative to recollect that any feed coming from outer sources may bring small scale living beings or parasites whenever gathered from outside waters (debased or dirtied) or if from creature starting point (for example worms from non-purified creature compost). Live feeds can be created at home level under more secure norms or can be heat-treated before being given to angle. Instances of live fish feed include:

- Duckweed and oceanic macrophytes. Duckweed is very wealthy in proteins and can be provided crude for up to 10percent of the every-day apportion. Nonetheless, macrophytes are less absorbable than detailed feed attributable to their higher fiber content, which would likewise build the measure of solids/squanders in the framework(Wongkiew et al., 2017).

- Crop deposits from aquaponics or different sources can be provided to herbivorous/ omnivorous fish in modest quantities.

- Earthworms are promptly possible from green manure heaps, particularly in provincial territories. A keep period from 1–2days is suggested if worms originate from outside sources so as to lessen the danger of bringing microscopic organisms into the framework (Rakocy et al., 2016).

- Insect hatchlings are wealthy in proteins, yet care ought to be taken not to utilize them in unreasonable amounts attributable to their higher lipid content. Hatchlings can be refined on spoiled natural issue (vegetables, organic products); in any case, a keep period from 1–2days is prescribed if the substrate contains material of creature cause (Nozzi et al., 2018).

- Insects can be given to omnivorous or meat eating fish species, however the nearness of the exoskeleton of chitin diminishes their edibility.

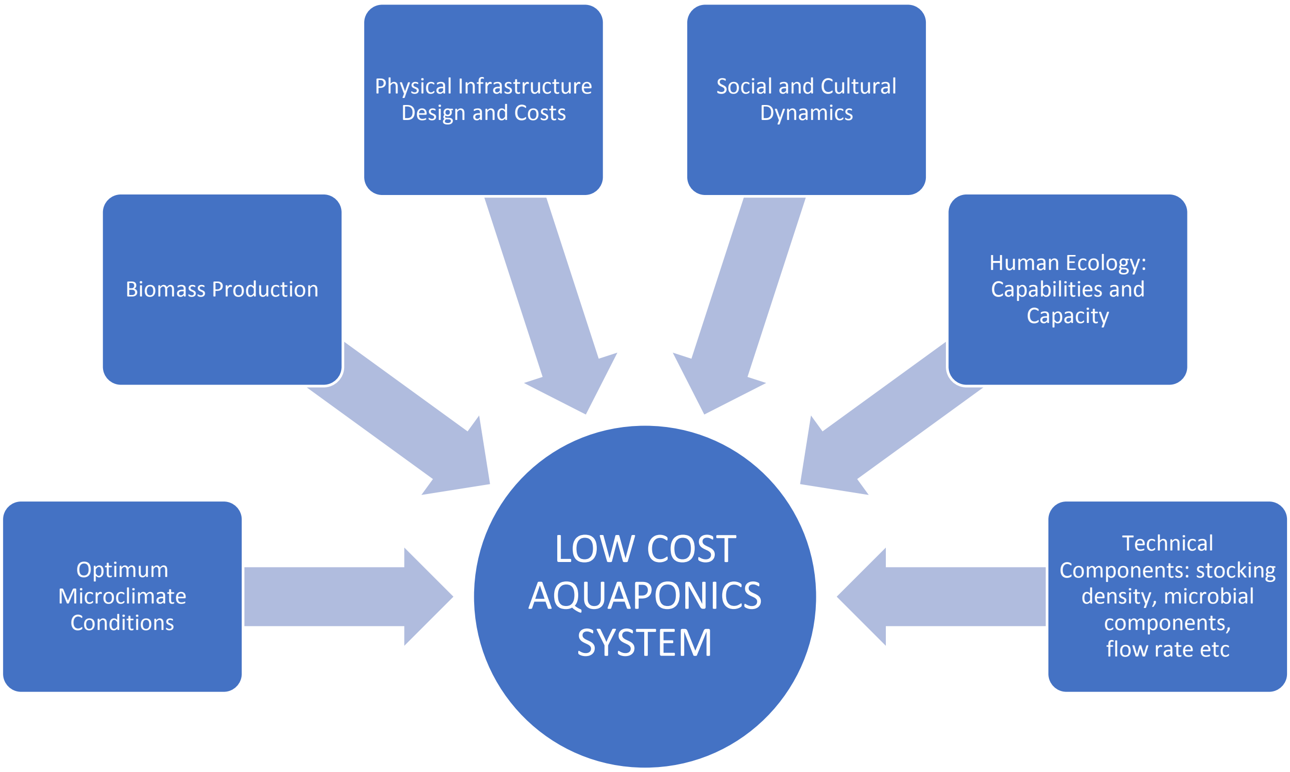
- Small fish, shellfish and molluscs are accessible from streams or lakes. In any case, judiciousness might be required attributable to the dangers of defilement and parasites. Algae can without much of a stretch be provided to herbivorous/omnivorous fish. Green growth can be developed in discrete tanks adjacent to the aquaponic framework.

Potential for pen culture improvement additionally exists and like the land-based aquaculture potential zone, these are to a great extent in the southern piece of the nation from the Ashanti locale and southern western pieces of the Brong-Ahafo district down to the waterfront zones where economic situations, foundation, backing and data sources are generally positive. Confine culture is one of the most quickly developing parts in aquaculture all the more broadly and has gotten significant consideration as a methods for escalated cultivating (Pillay and Kutty, 2005). It is anyway a rising division in Ghana and may should be supported, while simultaneously guaranteeing that natural limit issues were comprehended and applied. Preferences of confine culture over lake culture as delineated before incorporate the utilization of existing water bodies, relatively low capital expense, utilization of straightforward innovation, high stocking thickness, ideal feed use, improved development and simplicity of the executives (Hailu, 2008). Contingent upon profundity, exceptional returns of 100 – 2000 mt/ha/yr are achievable (Edwards, 2015). Notwithstanding, there are a few weaknesses, counting danger of burglary, low resilience of fish to poor water quality, danger of misfortune because of confine harm brought about by predators or tempest, reliance on healthfully complete eating regimens and more serious danger of infection episode. Serious creation as being proposed would require huge measure of data sources especially as seed and top notch feed. Prescribed stocking pace of tilapia fingerlings change contingent upon confine volume, wanted collect size, generation level and the length of culture period. Ideal stocking rate for creation of 250g tilapia will for example extend from 600 to 800 fish for each cubic meter; 300 to 400 to produce fish averaging 500g and 200 to 250 to deliver fish averaging 750g (Asmah et al., 2014). As indicated by (Rana et al., 2006)a humble 100mt tilapia confine unit may require around a large portion of a million fry and 150 to 200 tons of pelleted feed. Serious creation in a land-based framework focusing on a similar yield of 100mt with a stocking thickness of 5/m2 creating a normal fish size of 250g will require 400,000 fry (Asmah et al., 2014). Accessibility of value seed as set up from this investigation is anyway a significant issue with current supplies being described by high rate of in lake generation and low endurance rates. Issues with inbreeding will anyway not have any significant bearing in confine culture as the rearing cycle of tilapia is prevented in confines. Any advancement toward this path ought to anyway organize these sources of info which could be created through a public-private segment activity for effective administration and straightforward entry to funds. Too, albeit set up capital as demonstrated might be lower than land-based tasks, capital what's more, operational expenses can be high and accordingly access to accounts may likewise must be considered (Bostock, 2011).

6.5.2. Future Pathways

Aquaponics has numerous pathways that can still be explored in future studies, below is a diagram showing the pathways that can still be explored:

Figure 24: Diagram showing recommended studies for the future of aquaponics



Source: Author (2019)

6.8. Summary

The developing prominence of aquaponics has incited a few examinations of the financial aspects of these frameworks. The few investigations created to date show great potential for vegetables produced in aquaponic systems to be gainful, with the fish portion perhaps making back the initial investment or causing an overall deficit. Premium costs in very good quality markets will be vital for vegetables produced in aquaponics and fish to be gainful. Additional expenses and dangers related with these unpredictable frameworks must be broke down cautiously before putting resources into aquaponics.

Aquaponics is an advantageous reconciliation of two develop disciplines – aquaculture and hydroponics (AlShrouf, 2017). This specialized paper examines the three gatherings of living life forms (microorganisms, plants and fish) that make up the aquaponic biological system. It presents the executives procedures what's more, investigating rehearses, just as related themes, explicitly featuring the points of interest and inconveniences of this technique for nourishment creation. This distribution talks about the principle hypothetical ideas of aquaponics, including the nitrogen cycle, the job of microscopic organisms, and the idea of adjusting an aquaponic unit. It considers water quality, testing and sourcing for aquaponics, just as strategies and speculations of unit configuration, including the three fundamental techniques for aquaponic frameworks: media beds, supplement film strategy, and profound water culture.

The distribution incorporates other key themes: perfect conditions for regular plants developed in aquaponics; substance and natural controls of regular nuisances and sicknesses including a perfect planting guide; basic fish infections and related manifestations, causes and cures; devices to figure the smelling salts created and bio filtration media required for a certain measure of fish feed; creation of hand crafted fish nourishment; rules and contemplations for setting up aquaponic units; a money saving advantage investigation of a little scale, media bed aquaponic unit; a far reaching manual for building little scale variants of each of the three aquaponic techniques; and a concise rundown of this production structured as a supplemental present for effort, augmentation and training (Barron and Dasli, 2010). Aquaponics is an incorporated way to deal with effective and maintainable heightening of agribusiness that addresses the issues of water shortage activities. Comprehensively, improved rural practices are expected to mitigate rustic destitution and upgrade nourishment security.

Aquaponics is without build-up, and maintains a strategic distance from the utilization of concoction manures and pesticides. Aquaponics is a work sparing method, and can be comprehensive of numerous sexual orientation and age classes. Even with populace development, environmental change and decreasing supplies of water and arable land around the world, creating proficient and incorporated farming procedures will bolster monetary advancement.

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