The Aquaponics Project:

Improving Food Security in Namibia in the Face of Climate Change

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Hanns Seidel Foundation

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Abstract

We worked with the Hanns Seidel Foundation to improve food security in Windhoek, Namibia with aquaponics. We worked remotely with our sponsors to provide facts sheets, videos, a manual, and a prototype to aid in their Aquaponics Project. These deliverables will educate Namibians on the benefits of aquaponics and aid in the development of aquaponic systems throughout the country. We analyzed documents and conducted interviews to create our deliverables. We recommend our sponsors adapt our deliverables for use in their other global project sites.

Acknowledgements

We would like to acknowledge the many people who contributed to the success of our project.

We want to thank…

Our interviewees, Manny Barra, Paul Mason, Brent Meins, Joe Pate, and Jim Rugarber who were generous enough to speak to us over Zoom and email about their aquaponic systems. Their openness to share information on why they started using aquaponics, how they built their systems, and problems they have encountered greatly impacted our deliverables. It was also incredible that they were willing to share photos and videos of their aquaponic systems, it greatly improved our understanding of aquaponics.

Our sponsors at the Hanns Seidel Foundation, Clemens von Doderer, Lara Beer, and Burton Julius who continued to work with us on the Aquaponic Project through our inability to travel to Namibia. Their ability to adapt to change and communicate efficiently in a remote environment allowed us to create a successful project. As well, their constant feedback greatly improved the design of our deliverables.

Our advisors, Professor Doiron and Professor Stafford for their unwavering support our group throughout C and D term. Their flexibility, understanding, and support during the changing IQP experience and tips on how to work remotely provided us the opportunity to create a successful project. We greatly appreciate their creative ideas, such as Pau Hana, to make this unique IQP experience as normal and meaningful as possible. This project would not have been possible without their constant support and motivation.

Executive Summary

Introduction

In recent years, climate change and drought has negatively impacted Namibia's agriculture industry. In 2019, the President of Namibia declared a Drought State of Emergency. This drought has caused a 42% decrease in harvest production (UNICEF, 2019). This has had drastic effects on the food security of Namibians. Nearly 430,000 Namibians were estimated to be food insecure as of March 2020 (Food and Agriculture Organization of the United Nations, 2020). It is important that Namibia takes action to find more sustainable methods of agriculture, such as aquaponics.

Sponsors

We worked with the Hanns Seidel Foundation (HSF) in Windhoek, Namibia to create materials for their Aquaponics Project. The HSF has project centers in 71 different locations. They were founded in 1967 with the goal of "Service of Democracy, Peace, and Development." In Windhoek, the HSF works to educate the community on important topics such as climate change, climate-smart agriculture, and renewable energy. Their current initiative is the Aquaponics Project to combat food insecurity in Namibia. For our IQP project, we helped create materials that the HSF will use to teach the community about aquaponics.

Objectives

The goal of our project was to address the food insecurity of Namibia with the use of aquaponics. We aimed to produce educational information to teach the public about aquaponics and how they could build their own systems. As well, we wanted to extend this information to people across the world. To achieve these goals, we completed the following four objectives:

1. Provide educational information about aquaponics through fact sheets and videos.
2. Create a viable aquaponics prototype design for Namibia to improve food security.
3. Create a construction manual infographic and video based on the aquaponic prototype design.
4. Create a blog that shares information online about aquaponics and our project.

Methods

Data Collection and Analysis

To create our deliverables, we used qualitative data from online resources and interviews. The online resources used were journal articles, newspaper articles, blogs, educational websites, and government websites. They were found to contain reliable and universal information that could be applied to our project. The information we utilized was determined by the specific topics and leading questions that our sponsors provided for each deliverable. Our team also conducted several interviews with current aquaponic growers to gain more practical information on running a system.

To analyze the data that our team collected, we used a process called thematic coding. Thematic coding is the process of identifying common themes throughout the data collected to categorize the research. This establishes a framework of themes around the central topic, in this case aquaponics. These themes were the analysis of the information that we collected throughout our project and creation of our deliverables for HSF.

Deliverable Development

To create our deliverables, our team used an iterative design process. The iterative design process involves establishing what is needed to generate the deliverable, creating the deliverable, and then going through a feedback process. In the feedback process, the deliverable is revised until there are no more improvements, at which time, the final deliverable is produced. From our objectives, there were four main deliverables created. These were the blog, the fact sheets and related video, an aquaponics prototype design, and a manual infographic and related video. Using the iterative design process for these deliverables, we were able to create successful deliverables that fit our sponsor’s needs.

Findings

Themes

Throughout our project, we gathered information for our deliverables through online research, interviews, and feedback from our sponsors. Several themes emerged from our analysis of this data. *Table 1* shows the four overarching themes of information we found, Purpose, Economics, Yield, and Design, and their corresponding subsets lie underneath. These themes guided the information included in our deliverables.

Table 1: Breakdown of themes

Purpose	**Economics**	**Yield**	**Design**
Food Security	Investment	Crops	Design Factors
Sustainability	Market	Fish	System Parameters
Commercial/Revenue		Production Time	
Education			

Deliverables

We developed several deliverables for the Hanns Seidel Foundation's Aquaponics Project. These deliverables exemplify the themes discussed in the previous section. The deliverables created were:

1. Fact Sheets
2. Video Summarizing Fact Sheets
3. Aquaponic System Prototype
4. Manual Infographic
5. Prototype Construction Video
6. "Aquaponic Chronicles" Blog

These deliverables can be found on HSF's website, ThinkNamibia.org.na, and will aid in their initiative to educate Namibia on sustainable agriculture, as well as, informing the public on the benefits of aquaponics.

Discussion

Challenges

Due to the Covid-19 pandemic, our group faced numerous obstacles in the completion of our project. One major difficulty was the travel restriction, which resulted in us not being able to travel to Namibia. While this was a large challenge, we moved forward with our project and continued to work with the Hanns Seidel Foundation remotely from the United States. This resulted in small communication issues, as there is a six-hour time difference between our locations. However, our team adapted to these challenges and were flexible with the communication. We also adapted the framework of the project by implementing more online tools, such as creating the "Aquaponic Chronicles" blog, as well as utilizing Zoom to conduct interviews with aquaponics growers.

Recommendations

Our team has several recommendations for the future use of our deliverables for the Hanns Seidel Foundation. When planning to travel to Namibia and interact with young students, we spoke with a teacher about the best ways to engage students in lessons. The main takeaway was that the lessons should include games and interactive elements. Therefore, we recommend to the HSF that students have hands-on experience, so they are more likely to be engaged in what they are learning. This can be done by having the students help build the aquaponics system and later harvest the crops. For the fact sheets, manual, and videos, we recommend that the HSF include these within their lesson plans while at the school. We also recommend that these documents are made easily accessible to and be advertised to members of the community who are interested in learning more about aquaponics to improve food security. Our team also believes the HSF should use these deliverables in more locations than just Namibia as they are a global organization with more than 70 worldwide locations and the information in our deliverables can be easily modified for different locations allowing for my agricultural production in other food insecure countries. Finally our group recommends the HSF implement our small scale prototype design in some way when constructing a system in a Namibian school as it is relatively simple and students would be able to more easily construct it than the large scale design that will currently be installed.

Future Implications

Due to the COVID-19 pandemic, parts of the HSF's Aquaponics Project are currently put on hold until quarantine is lifted. Once it is safe to do so, the HSF will continue with their plans to teach and build an aquaponic system in a local Namibian school to allow younger students to learn more about topics like sustainability, food security, and agriculture. This system will also teach the kids about aquaponics and how they could build and maintain a system at home.

Although we were not able to work with the HSF as they build the prototype aquaponics system, we were able to continue our work with them remotely and provide them with tools to teach individuals about sustainable methods of agriculture. In the future, these materials can provide tools for anyone to improve their own food security through aquaponics.

Authorship

Paper

	Construction	Revisions
Abstract	Sophie	All
Acknowledgments	Sarah	All
Executive Summary	Nicholas	All
Introduction	Sarah	All
Background	All	All
Methodology	All	All
Findings	All	All
Discussion	Sophie	All
Formatting	Sarah	All

Deliverables

	Construction	Revisions
Fact Sheet #1	Mary, Nicholas	All
Fact Sheet #2	Sarah, Sophie	Sarah, Sophie
Fact Sheet #3	All	Sarah, Sophie
Fact Sheet Video	Mary, Sarah	Mary
Prototype Design	Nicholas	Nicholas, Sophie
Manual Infographic	Sophie	Sophie
Manual Video	Sarah	Sarah
Blog	Mary	All

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Chapter 1: Introduction

Namibia has been facing its worst drought in several decades, with a Drought State of Emergency being declared in 2019 (UNICEF, 2019). Namibia's agriculture industry, which accounts for 31% of the labor force, is greatly impacted by this drought (Central Intelligence Agency, 2020). In recent years, crop yields have been low due to low amounts of rain. In 2013, the drought killed 4,000 animals and affected nearly 300,000 people (UNICEF, 2019). As climate change continues to affect the agriculture industry, Namibia becomes more reliant on food imports and food security continues to worsen. An estimated 430,000 Namibians are in the Crisis or Emergency stages of food security (Food and Agriculture Organization of the United Nations, 2020). New and innovative agriculture methods are needed to improve these worsening conditions in Namibia.

The Hanns Seidel Foundation (HSF) is looking to promote sustainable agriculture in Namibia to help improve food security. Aquaponics, when used in addition to hydroponics and traditional agriculture, would greatly improve the food security of many Namibians. This is because aquaponics provides leafy greens and fish in a sustainable and water efficient system. Due to the ongoing drought in Namibia and the arid climate, water is scarce in the country. In 2019, the drought caused a low harvest that severely affected subsistence farming. This led to food insecurity worsening in early 2020 (Food and Agriculture Organization of the United Nations, 2020). The effects of the drought show that it is imperative for Namibia to implement climate-smart agriculture practices. By changing current methods of agriculture to a more water efficient and climate resistant method such as aquaponics, rural Namibians can improve their food security.

Several efforts in Namibia have addressed issues caused by climate change on food security and agriculture. Namibia's Climate Change Policy strives to protect the agriculture industry by achieving sustainable agriculture production. The policy does this by promoting highly adaptive breeds of livestock and crop cultivars, conservation agriculture and ecologically compatible cropping systems, and agricultural production that will best maintain and improve household income (Ministry of Environment & Tourism, 2011). Climate-smart agriculture, or agricultural methods that can provide sustainable food security within the effects of climate change, has been promoted by the Food and Agricultural Organization of the United Nations and the HSF (Food and Agriculture Organization of the United Nations, 2020). These efforts are working towards improved agriculture methods for Namibia while it faces the harsh effects of climate change.

Although these efforts are working towards a similar goal of improving agriculture methods in Namibia, none fully address aquaponics. Aquaponics is a sustainable method of agriculture that is perfect for dry and arid climates such as Namibia. It is more water efficient than traditional agriculture methods and can provide better crops during the drought. Promoting aquaponics in Namibia will create a new type of climate-smart agriculture for them to utilize.

The goal of this project was to create educational materials and a prototype system to promote the use of aquaponics in Namibia. This goal was achieved through four main objectives. We first created educational materials in the form of fact sheets and videos, developed a prototype aquaponics system, created a manual infographic and video of the system, and developed a blog to share aquaponics information. This information was shared on the HSF's website, ThinkNamibia.org.na, as part of their aquaponics project initiative. It provides all the information needed for Namibians to learn about aquaponics and build your own system. These deliverables will aid in improving Namibia's food security in the face of climate change.

Due to the COVID-19 pandemic, we were unable to travel to Windhoek, Namibia to complete the project. We have altered parts of the project to complete as much as we can virtually. The fact sheets, informational video, and infographic have remained the same. Originally, the prototype aquaponic system was to be built in a rural Namibian school as a teaching material and to provide the students with food. Due to the lockdown in Namibia, we instead developed a design in CAD to create the infographic and video manuals. This will allow the Hanns Seidel to have the materials needed to teach and build aquaponics systems in Namibia when possible. As well, we added a blog to our project due to the implications of COVID-19. We saw a great opportunity to share information online during this time. We used this to interview several aquaponic hobbyists and share what they have done to spread the knowledge and benefits of aquaponics. Despite these unpredictable changes, we were still able to provide useful deliverables for the HSF to use when promoting the use of aquaponics in Namibia.

Chapter 2: Background

2.1 Apartheid History

To understand how Namibia's agriculture system has been shaped, it is important to understand Namibia's Apartheid history. As Namibia started to seek independence from South Africa in the late 1900s, the country faced a series of challenges which impacted the economy, employment rates, and food security. Namibia became fully independent in 1990 after a long history of discriminatory and corrupt ruling. The discrimination and corruption left behind by South African rule has resulted in a lack of jobs and insufficient food for Namibians today. Before independence, Namibia was a part of South Africa but divided into an "Apartheid State," meaning "Separate State" in Afrikaans. This left Namibia in a segregated state that discriminated against native Africans. This inequality was the basis of the government and was a guiding principle throughout the country which inevitably led to economic disadvantages. The impacts of this discrimination can still be seen today, as South Africa left the newly independent country in a fiscal crisis, dependent on imports, partially developed, and segregated (Freeman, 1991). This placed Namibia at a disadvantage from the start of their independence. As well, South Africa remained in control over Walvis Bay at the time of independence. This bay is the most crucial port in Namibia and is relied on for almost all exports and imports. Walvis Bay's value is evident in South Africa's reluctance to leave it. In fact, the terms of Namibia's independence restricted the country as well as limited their growth. Their movement towards real independence and development within the first year was minimal (Freeman, 1991). Namibia was finally independent, however they lacked control over one of the most vital sections of their economy.

Not only have Namibians been very dependent on trade throughout history, but they have also developed their livelihoods off agriculture. Cattle have been a longstanding essential facet to their economy. On the surface this may seem like a result of the country's location and natural resources, but there is a deeper reason for the agricultural sector. The apartheid policies changed the way the Namibian people had to sustain themselves to survive, which changed how the economy needed to function and develop. Looking at the northwest region of Namibia before 1915, the economy consisted of trade with its surrounding lands. The pastoral economy was a part of regional trade networks. Then with the transition into colonial power, the 1920s brought a forced dependence on subsistence livestock husbandry. This form of production was their only means of economic security and limited the people and cattle's spatial mobility. It isolated Namibian farmers and resulted in many unforeseen consequences. The cattle population rose exponentially on the small amount of land with limited resources and many of the cattle became susceptible to disease and infection. The market that the Namibian people could sell to was also very limited. Many of the white settlers would not buy cattle from Namibians due to how they were raised, who they were raised by, and the quality of the cattle. Along with this, the land that the farmers were on became extremely depleted and by the 1950s it was noticeably overgrazed. Previously to the apartheid state, the cattle could have been sold to commercial ranches or traded with neighboring lands. This would have caused the cattle to keep moving around the country, however, due to the apartheid state they became stagnant in the native Namibians' allowed domain. The marginalized Namibian people were further forced into economic underdevelopment (Bollig, 1998). The lasting impact of these policies can be seen within the economic structure of Namibia today.

2.2 Economic Structure

Since Namibia's independence in 1990, the effects of apartheid rule can be seen in every aspect of Namibian life. Although Namibia has grown tremendously in terms of its economics, the years of struggle are still evident. It can be seen in the current levels of poverty, unemployment, and inequality in the country. The economic inequality of Namibia is represented by the Gini coefficient, which measures the income distribution among a population, or rather the wealth distribution. In the mid-90s, post-independence, Namibia had a Gini coefficient of 0.7 which was the largest of any country. Then in a government report which was released in 2008, based on data from 2004, the Gini coefficient shrunk to a value of 0.63. While the number did slightly decrease, the status of having the largest economic inequality did not (Jauch, 2012). This shows the continuance of economic inequality, which is also demonstrated by the country's Gross Domestic Product (GDP) documentation (Levine, S., & Roberts, B. 2013). Another way to understand the well-being of the Namibian people is by looking at the Human Development Index, a statistic that is used to measure the well-being of a country's people by accessing their choices in life. This reflects how much a country has or is currently developing. In 2011 the United Nations Development Programme (UNDP), Human Development Report, showed that Namibia had a Human Development Index of 0.625. On the surface, this is a very good number for a country to have. However, when economic inequality was factored in, the value decreased by 43.5%. This decrease shows the continual influence of economic inequality, which is a direct relation to the colonial power in Namibia (Jauch, 2012). These values show how strong the inequality in Namibia is and help to understand the current economic structure in Namibia.

Economic inequality is exemplified within the unemployment rates of Namibia. They are incredibly high. In the 2008 Namibia Labour Force Survey (NFLS), Namibia's output per worker, otherwise known as labour productivity, was US $21,998. This value was greater than any other country. However, this is not reflective of the average Namibian person's life. Its people are not all prospering. As the economy of Namibia grows, it can increase its Gross Domestic Product (GDP) output. However, the large unemployment rate, growing population, and no new job creation is not leading toward economic success in Namibia. The 2008 NLFS also showed that the unemployment rate was 51.2%. This was the largest unemployment rate surveyed out of Botswana, Lesotho, Mali, Namibia, Kenya, South Africa, Zambia, and Sub-Saharan Africa. With agriculture being a large portion of employment in Namibia, it is also useful to consider how employment has changed specifically within this sector. From 2004 to 2008, agricultural employment has declined 49% and fishing employment 89% (Mwinga, 2012). So even though the country has gone through economic growth since its date of independence, employment rates have continued to decrease.

Today, Namibia is considered a lower-middle-income country. It has one of the most unequal income distributions in Africa, due to the large amount of unemployment, poverty, and food insecurity. With the evolution of political and social change, the economy has adapted and evolved. Today, the country's economy consists of two major sectors: the modern market and agriculture. The modern market, of imports and exports, contributes to 90% of the country's GDP. They export many raw materials and import their consumer goods. While this may make it seem like agriculture is unimportant, quite the opposite is true. Despite agriculture only contributing to 5% of the country's GDP, 70% of the population depends on agriculture for their livelihood. Within Namibia's agricultural system there is both commercial farming and subsistence farming. Commercial farming is what contributes to the country's wealth, whereas subsistence farming is how many Namibians support themselves, establishing their own food sources. The Namibian economy is still growing and in its early stages of development. It is highly trade dependent which causes its sectors to be interdependent. Each sector depends on each other in order to function properly. This interdependence causes it to be difficult to predict how the economy will grow and evolve. Investment in one sector could enhance the whole economic system and cause it to expand at rapid rates (Humavindu & Stage, 2013). The complexity of the economy continues to affect the lives of Namibians.

2.3 Climate Change

Agriculture is a large part of the Namibian way of life, economics, sustainability, and history. In 2011, it was documented that 24% of the GDP was from its agriculture, fisheries, and mining. It was also concluded that 61% of Namibians use subsistence agriculture to obtain a livelihood. Because of the huge dependence on agriculture and fishing, global warming and climate change are important issues to address. The variability of climate change could threaten the entire societal structure of Namibia. Signs of climate change can be seen in the historical trends of increasing daily maximum temperature, the increase in heavy rainfall scattered by dry periods, and the frequency of droughts in the country. There is a prediction that by 2020 the rainfall and evaporation will have increased by 30% due to the increase in dry climate (Siyambango, Kanyimba, & Mufune, 2015). Drought and water availability pose a large issue for the Namibian agricultural system. It is causing farmers to struggle feeding their cattle due to the land becoming barren and depleted of grazing plants. It also inhibits crop growth. As of October 2019, Namibia extended their state of emergency by six months and allocated N$570 million to help drought affected farmers. N$138 million is specifically going towards a livestock support program. While not all farmers have seen this money, it shows the undeniable affects the drought has had and will continue to have on the Namibian way of life (Brandon Van Wyk, & Loide Ambondo, 2019).

It is imperative that the local people of Namibia are aware of the effects of climate change. It can affect the way they structure their agricultural decisions both on a personal and national level. In terms of making these decisions for the greater community, it is important to understand who is involved and what they believe. There is currently a large array of cultural views and interpretations of climate change in Namibia. The first dominant viewpoint is that the world is reaching its breaking point and the end is near. The second dominant viewpoint is that climate change is a direct relation to the way in which the world is operating, and a solution must be found. Most Namibian people have what is known as indigenous knowledge, which informs their position on climate change. Indigenous knowledge is the knowledge that they have developed based on observations of the environment from living on the same land for a long duration of time, such as several years, an entire lifetime, or even several generations. They develop this interpretation of climate change based on how they have seen the world evolve. The rural societies have seen changes in the amount of precipitation, droughts, and increases in natural events. This indigenous knowledge helps them make decisions in terms of food security, resource management, flood, and drought actions. Allowing their communities to evolve in the face of climate change (Siyambango, Kanyimba, & Mufune, 2015). The severity of climate change continues to take a toll on Namibia agriculturally, socially, and economically.

2.4 Namibia’s Agricultural Methods

It is important to understand the current state of agriculture and food consumption in Namibia to understand the need for improvement within agricultural systems. Currently, there is a stark contrast between the agriculture in the north and south of Namibia. The difference is due to the rainfall each region experiences. The rainy north has land more suitable for farming while the dry south has land more suitable for ranching. Throughout the country, there is also a mix between commercial and communal farming. Commercial farming is used to provide food for the market. It is controlled by approximately 4,000 large, white owned farms in central and southern Namibia. Communal farming prevails in northern Namibia, as well as the former reserves in central and southern Namibia. In these areas they use traditional, small-scale farming methods for self-consumption, also known as subsistence farming (Elkan, van der Linden, Andima, Sherbourne, & Amutenya, 1992).

The agricultural methods directly relate to the diet that is available for the people of Namibia. Like many poor countries, starchy foods are widely eaten, the most popular being millet and maize. Due to the abundance of livestock, meat is also widely eaten within Namibia. To provide for themselves, rural households typically have their own cattle, goats, and sheep. They also take part in game hunts, which occur everywhere for self-consumption as well as for commercial sale. Along with starches and meats, the rainier north also produces beans, pumpkins, spinach, berries, and nuts which provide another source of nutrition. Fruits and vegetables as a whole are not very popular in Namibia. There is not a large amount of availability or variety, even though they are commercially produced along the Orange River. Along the northern rivers of Okavango, Zambezi, and Chobe, and the western coast, fishing is an important practice that provides protein for both self-consumption and sale (Elkan et al., 1992). Behind agriculture and mining, fishing is the third largest sector of the economy and is also the second largest export earner. Species such as sardine, anchovy, herring, tuna, and Cape horse mackerel are commonly fished (Boyer & Hampton, 2001). Diets within Namibia are diverse to a certain extent, as there are the limiting factors of the lack of fruits and vegetables and the dependence on weather.

Families within Namibia feel the impact of climate change through the shortage of fresh, locally grown foods and lack of diversity in diets. In an interview conducted in 2010, one family stated, “Even when there is something to eat, which in most cases is *mahangu* or maize porridge, your hunger is not satisfied. Every day we eat the same meal, pap, pap, we do not have a choice of what we want to eat, it is what we can afford (Pendleton, Crush & Nickanor, 2014).” This shows the lack of nutritional diversity that Namibians face. This interview also addresses the lack of food due to affordability. Namibia's dry climate and limited water supply poses an issue when it comes to growing fresh produce. The country often solves this by importing these goods from other countries. When they are imported it increases the prices causing both rural and urban families to not be able to afford the food. Namibia needs agricultural improvements to make food diversity more affordable for the larger population.

2.5 Relocation and Urban Agriculture

Since Namibia gained its independence thirty years ago, Namibia has gone through fast urbanization. It has increased the freedom of migration and ability to live in Namibia, leading to food insecurity for the poor urban population (Pendleton, Crush & Nickanor, 2014). The influx of immigrants in the country has been mainly in northern rural communities. This has led to difficulties in finding food for migrant and local families. Most individuals move to the city to seek job opportunities, but these opportunities are not there. This creates an environment where families are faced with the challenge of finding work, as well as limited affordable food, further increasing food insecurity as access to jobs is a direct determinant of food security (Pendleton, Crush & Nickanor, 2014). With the challenges to find work and the lack of land and resources to grow crops, food security is not common within the city. This is not to be confused with access to food as food availability is not a concern in Windhoek due to the development of supermarkets (Pendleton, Crush & Nickanor, 2014). Urban people tend to purchase most of their food in stores, that consists mainly of imports and crops from central and southern commercial farms. The high price of food caused by the imports makes it difficult for many families in rural and urban communities to afford it. Like most of the country, there is a lack of local fruits and vegetables in Windhoek due to the climate most of the produce available is imported from South Africa. However, people practicing urban and peri-urban agriculture will produce these crops, so it is important to understand how they may do this despite the challenges. According to a study on urban and peri-urban agriculture from 2002, most people gardening in Windhoek bring experience from rural areas to provide food to family members. They tend to base their farming practices on land preparation, planting, weeding, and harvesting. They typically produce vegetables only in the winter and have a wide range of crops such as maize, beans, and fruit trees. Livestock are limited to small animals and poultry due to the lack of space and fishing remains a seasonal activity. There are many ways in which these practices could be improved and many producers in Windhoek hope to expand their vegetable production (Dima et al., 2002).

2.6 Relationships

Rural people typically practice subsistence farming, meaning they grow their own food supply. While these communities face climates not ideal for growing crops, they are able to find ways to work with their environment to produce food. It is common for rural families to send food to relatives in urban areas, such as Windhoek, to provide them with food since they do not have the ability to grow crops (Elkan et al., 1992). A man from Windhoek spoke about his connection to his rural family and the agricultural relationship they have, saying:

> “There are some relatives in the rural north who send us food and especially when harvests are good we receive a variety of food types apart from *mahangu* flour. We do not receive this food on a monthly basis – but when we receive it, it relieves me from going to the shops every time to buy food (Pendleton, Crush & Nickanor, 2014).”

It is evident that this relationship is essential for urban families. In return for the food, they send a portion of the money they have made, if they were able to find work. Throughout the year, many people in rural communities also need to rely on purchased food when the environment is no longer suitable for farming. For these people in the communal farms and rural reserves, cattle are typically used as a way to store their wealth, so they are only slaughtered and sold when needed to purchase food in these tough times (Elkan et al., 1992). The relationships between urban and rural communities help mitigate food insecurity within the country, but climate change has made farming increasingly difficult to supply enough food for a family.

The Windhoek community is very active when it comes to receiving support from rural relatives to establish food security. From a study conducted in 2014, 37 % of food insecure homes had access to crops from rural relatives. This emphasizes the dependency on food transfers for urban households who are unable to afford food. However, even with these supplements, the homes are still considered food insecure. When studying food secure households, or homes that have sufficient amounts of food, it was noted that only 6% were receiving transfers (Pendleton, Crush & Nickanor, 2014). Although these transfers work to combat food insecurity, they alone are not enough. One urban citizen states, “It is not always but maybe once in 2 months [that we have grain] and the quantity depends on how much they have in their granaries (Pendleton, Crush & Nickanor, 2014).” The relationships between urban and rural families is not a reliable source of food security for the Namibian people. They depend too highly on the quantity and quality of food grown from the rural communities. Therefore, as growing conditions become harsher in rural areas due to floods and droughts, food insecurity in Namibia is expected to worsen if no changes are made.

2.7 Aquaponics and Its Relation to Food Security

A solution to some of the current issues found in Namibian agriculture may be found in aquaponics, a modernized way to combine both traditional aquaculture and hydroponics. Sylvia Bernstein’s (2011) book on the subject defines aquaponics as:

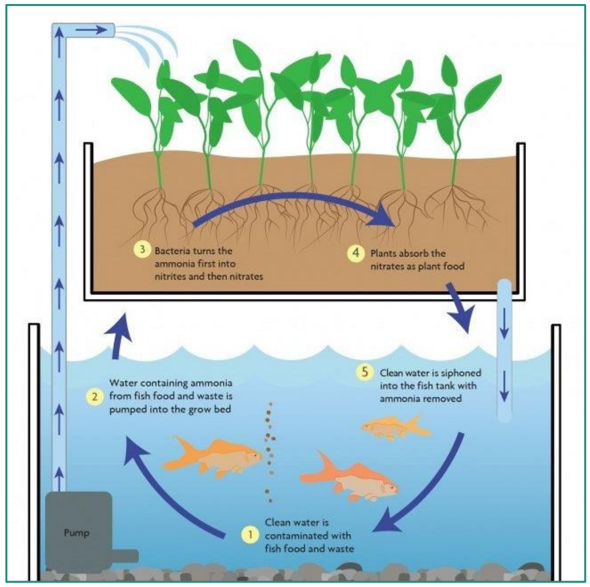
> “The cultivation of fish and plants together in a constructed, recirculating ecosystem utilizing natural bacterial cycles to convert fish waste to plant nutrients. This is an environmentally friendly, natural food-growing method that harnesses the best attributes of aquaculture and hydroponics without the need to discard any water or filtrate or add chemical fertilizers.”

To understand aquaponics and its relation to improving food security, you must first understand the two major cultivation techniques that were combined to produce it, hydroponics and aquaculture. Hydroponics is the cultivation of plants without soil, typically achieved through a nutrient-dense water running through the roots of plants suspended in a growing media such as perlite, gravel, shale, sand, or sawdust (Stauffer, 2006). The main benefits of hydroponics include the ability to grow food in non-arable regions, such as Namibia, as well as in many different climates due to the highly controlled nature of growing food in hydroponic greenhouses, with everything from nutrient content to light schedule being controlled by the farmer. Hydroponic systems also have downsides. There are expensive nutrients that must be mixed with water and the water must be replaced occasionally due to salinity build up.

Hydroponics is also quite labor intensive. It is necessary for farmers to test the properties of their water daily to ensure the correct nutrients are being supplied to the plants. This all leads to expensive maintenance costs for a hydroponic system. The other component of aquaponics is aquaculture, which is the cultivation of aquatic animals or plants, especially fish, in natural or controlled marine or freshwater habitats. A recent development that has made aquaculture more efficient is known as recirculating aquaculture systems, or RAS (Bernstein, 2011). These RAS systems are man-made tanks, densely packed with fish that rely on the system's ability to draw carbon dioxide and waste from the water while also aerating it, to create an optimal environment for fish survival (Ebeling & Timmons, 2012). This method of fish cultivation has significant drawbacks when used with traditional cultivation methods, as these high-packing densities of fish require a constant source of power. If the filtration system were to shut down, many fish would die within hours from oxygen loss. When both hydroponics and aquaculture work in conjunction, they can mitigate each other's weaknesses. You can see how these systems work in conjunction in *Figure 1*. The fish waste that was an unnecessary byproduct in aquaculture becomes a valuable replacement for chemical nutrients in aquaponics. Aquaponics also takes notes from nature, making each system its own small ecosystem, complete with animals, plants, and microbial organisms that will naturally balance the system in the way a hydroponic farmer would need to manually do each day. This greatly minimizes the amount of work required to keep the system viable. All these positives make aquaponics a much more viable option than the cultivation techniques that make it up, especially for an arid and relatively non-arable country, such as Namibia.

Figure 1: Aquaponics system cycle

(Source: Helvey, 2009)



2.8 Various Methods for Aquaponic Systems

There are several different methods of setting up an aquaponics system, each dependent on the needs of the user. Primarily, there are three different types of aquaponics system designs: Nutrient Film Technique (NFT), Media Bed, and Deep Water Culture (DWC) (Goering, 2019). NFT, shown in *Figure 2*, is prevalent in commercial aquaponics production due to the space efficiency of this method where plants are grown on vertical "shelves." One drawback of this method is that it is mostly limited to growing leafy greens due to the root structure of larger crops clogging the irrigation or being too heavy for the shelving. This method also makes the system more prone to temperature swings because more of the roots are exposed to the air.

Figure 2: Nutrient Film Technique System
(Source: The surprising benefits and types of aquaponic systems, 2015)

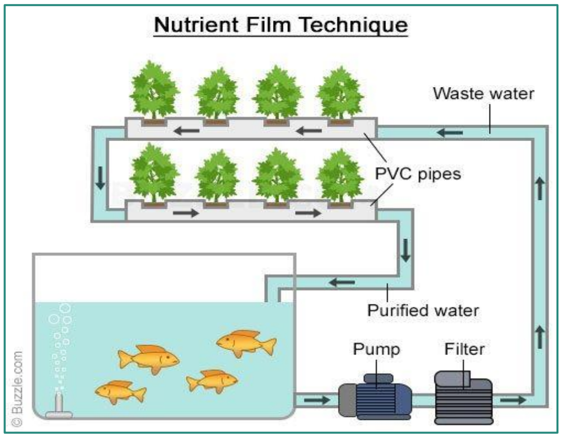
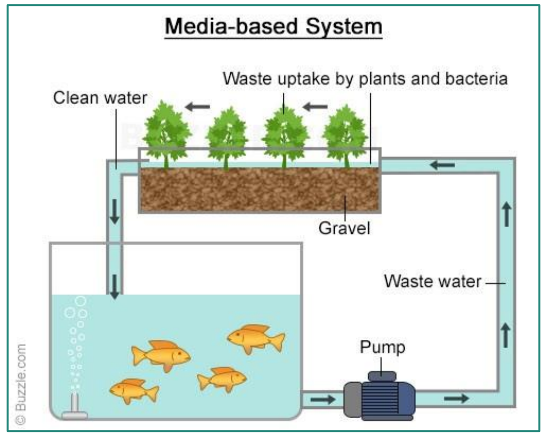


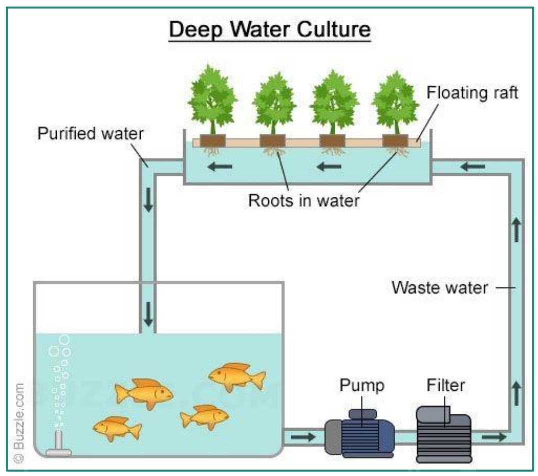
Figure 3: Media-based System
(Source: The surprising benefits and types of aquaponic systems, 2015)



Media bed aquaponics, shown in *Figure 3,* is much more accessible for a beginner user, as they are relatively simple to fabricate, cheap in terms of materials, and productive even at a small scale. This involves suspending the plants in a relatively densely packed media such as gravel, shale, or sawdust and pumping the wastewater from the fish tank into the media to have it then drain back into the tank for recirculation. Since the media in this case supports roots in the same way soil does in traditional agriculture, larger plants such as fruits, vegetables, and flowering plants can be effectively cultivated in this type of system. The lack of efficiency in terms of space, however, means this method does not scale well for commercial production.

DWC, shown in *Figure 4*, relies on suspending plants on floating rafts in such a way that their roots will be suspended in nutrient-dense and oxygenated water. Deep Water Culture is commonly found in commercial aquaponics, as the high volume of nutrient dense water the plants are suspended in makes the system more resilient to temperature change. The rafts used also allows for a very wide variety of plants, as the root zone can be as large as the tank the plants are suspended in. The lack of media, however, adds a higher upfront cost because without natural filtration via the media beds, costly filtration pumps must be installed for the system to operate. Each method has its pros and cons, making them viable for different types of production.

Figure 4: Deep Water Culture System
(Source: The surprising benefits and types of aquaponic systems, 2015)



Most systems have drawbacks related to temperature fluctuations. In an open-air system, these temperature changes can lower or destroy crop yield. However, this issue can be completely disregarded by growing in a greenhouse. A greenhouse is a controlled indoor environment optimized for growing. Many are outfitted with temperature regulation systems and backup lighting to get the highest possible yield per season. While a greenhouse does help for optimizing production, the additional cost for building and maintaining the greenhouse may outweigh benefits, unless the system intends to be designed for commercial production. Each of these systems has their benefits and drawbacks, and each user will need to determine which system will fit their needs best.

2.9 Benefits of Aquaponics

Some benefits an aquaponics system has over traditional cultivation methods of crops and fish include water efficiency and environmental sustainability. Daily water loss in an aquaponic system ranges from .5-5% of the total volume of water in the tank from evaporation, fish splashing during feeding, and excess sludge removal (Maucieri et al., 2017). This is a great improvement over traditional agriculture in fields where all water used is lost into the groundwater after watering. This makes aquaponics inherently more viable than traditional farming in arid regions and areas stricken by drought, such as Namibia. This also contributes to sustainability of the system as globally water use from agriculture accounts for nearly 70% of global freshwater use. Increasing the water efficiency involved with farming makes the process more sustainable for countries that face the risk of drought. Aquaponics also does not use petroleum products in the same manner as traditional farming methods. Using current methods for agriculture, the price of petroleum is directly tied into the price of food as tractors, fertilizers, and pesticides are all fabricated from petroleum products or rely on them to function (Bernstein, 2011). This direct tie between oil and food prices can lead to food prices increasing along with the ever-rising cost of oil, making food less available for poorer citizens or nations. Aquaponics is not perfect in this regard either, with the heating of tanks and powering of pumps also requiring energy that is typically generated by combustion of fossil fuels to operate. However, many gardeners have transitioned their systems to renewable energy via geothermal, solar, or wind power (Bernstein, 2011). Also, since there is no tilling of fields or weeds, there is no need to buy tractors or herbicides that rely on or are derived from petroleum. The fertilizer comes directly from the fish waste, so no petroleum products are used in enriching the plants with nutrients. Aquaponics uses much fewer fossil fuels in the cultivation of crops than traditional agriculture, making it more sustainable for a world slowly shifting focus to renewable sources.

2.10 Online Educational Resources

Improvements in technology have made online educational resources become more popular and accessible. Online educational resources can come in many forms, such as remote calls, websites, blogs, and social media. There are several benefits to sharing educational information online. One benefit is the ability to access people across the globe. This allows us to share information on the benefits of aquaponics to a wider audience. One example is, whether you live in the US or Australia, the internet allows for everyone to have access to the same information. Online applications also allow information to be shared at no cost. There is no need to spend money on physical supplies, such as paper for pamphlets, booklets, or manuals. Online educational resources have truly changed the way in which the world learns.

When creating online educational materials, there are important aspects to consider. First, it is important to determine what the goal of the material is. Once this is established, the design can then be made around the goal, tailoring it towards its intended audience. This will allow for the material to be as effective as possible. Another critical piece is the information within the educational material. It is important to provide rich information that is supported with reliable sources. The material must also be well designed and intuitive to the audience. This can be in terms of color choices, material choices and the way in which other media is incorporated. If these key components are taken into consideration when making online educational material, it will allow for the information to be accessible to the greater audience (Reed, 2020).

Chapter 3: Methodology

The goal of our project was to address the food insecurity of Namibia with the use of aquaponics. We aimed to produce educational information to teach the public about aquaponics and how they can build their own systems. We worked to enable the average person to have better food security when faced with the effects of climate change in Namibia. As well, we wanted to extend this information to people across the world. To achieve these goals, we completed the following four objectives:

1. Provide educational information about aquaponics through fact sheets and videos.
2. Create a viable aquaponics prototype design for Namibia to improve food security.
3. Create a construction manual infographic and video based on the aquaponic prototype design.
4. Create a blog that shares information online about aquaponics and our project.

This chapter will explain the specific steps and methods we will take to achieve the above objectives. To efficiently complete these objectives, our team chose to implement the agile design and iterative design processes while working on our deliverables. These processes and how our team implemented them are described in the following section. Then, the methodology for data collection, data analysis, and each deliverable is described.

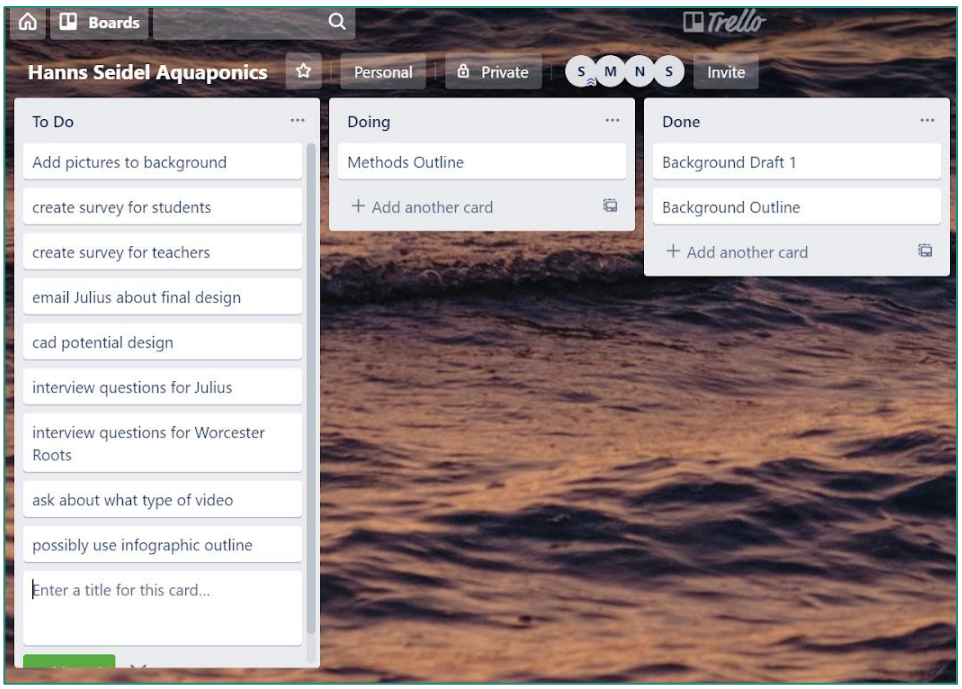
3.1 Team Dynamic

We established clear expectations for how our team would work during the project. For this, we chose to implement aspects of the agile process for our team dynamic. The agile process originated in software development and emphasizes the need to be flexible with the key aspects of planning, revisions, and communication.

The agile process involves a daily “standup” meeting. In this meeting, each team member discussed what he or she had done since the previous meeting, what they were currently working on, and what they would have done by the next meeting. This helped us communicate our accomplishments to each other and held each person accountable to their expected contributions. We also used this time to share any problems or roadblocks that we faced, which allowed us to discuss solutions.

To stay organized, we established a dashboard of our daily tasks. We used Trello, which is a site that allowed us to visualize what needed to be done, what was being worked on, and what had been done, shown in *Figure 5*. The deliverables were broken down into smaller tasks that were assigned to a team member each day. The tasks were represented on “cards” that would be moved depending on their status. During each “standup,” we set our goals and tasks for the day. Typically, in the agile process, the tasks are rated with poker numbering. We chose to instead discuss the daily tasks and break them up as we saw fit, without the rating.

Figure 5: Our Trello Dashboard

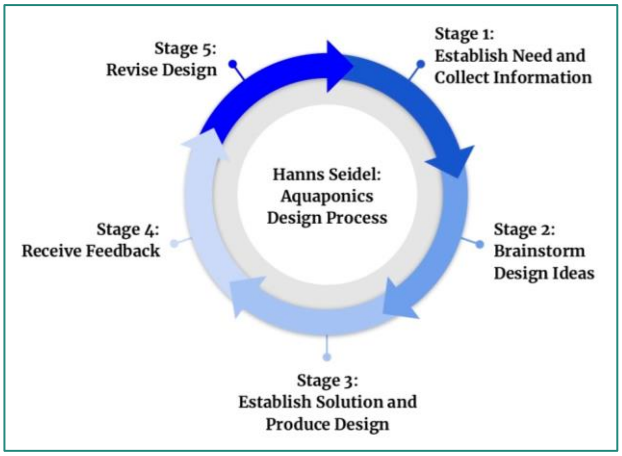


3.2 Iterative Design

To create our deliverables, we used an iterative design process. The iterative design process is a cycle of steps that starts with creating the first iteration, or draft, of the deliverable. Then, the draft is evaluated and revised until there is a final product. The benefit of this process is that we were able to go through it several times until the finalized design is established. Receiving feedback on our work was imperative in the development of an effective final design.

The iterative design process we used is depicted in *Figure 6*. It comprised five different stages. In stage one, we established the need for the deliverable and collected pertinent

Figure 6: Iterative Design Process



information. In other words, this stage revolved around establishing the goal that we were addressing with this aspect of the project and then collecting the necessary background information. In stage two, we brainstormed design ideas. When brainstorming, the goal was to collect every idea that we could think of in preparation of stage three. In stage three, after weighing all the options, we concluded what the best design solution was. It was important that we chose a design that considered the need of the objective. We then produced the first draft of the deliverable. In stage four, we received feedback on the design of the draft from our sponsors. We received feedback on the composition, logistics, information, user friendliness, and feasibility. In stage five, we revised our design based on the feedback. Stages four and five of the process were completed several times for each deliverable until data saturation was reached. Data saturation is when there is no new information or feedback gathered after stage four. We reached this endpoint in the design process when our sponsors told us that their needs were met, and they were satisfied with the design. When this was accomplished, we determined the final design of the deliverable.

3.3 Data Collection

Qualitative data was needed to create the deliverables of the project. This qualitative data was collected through online resources and interviews. The online resources used were journal articles, newspaper articles, blogs, educational websites, and government websites. Our sponsors outlined specific topics and guiding questions for each deliverable that guided our research. We then used online search tools to find the information needed. Before choosing to use a source, we first had to determine whether it was reliable or not. Typically, newspaper articles, peer-reviewed journal articles, books, and .org websites are the most reliable. We then had to determine if the information was pertinent to our deliverables. To do this, we would collect more information than necessary and organize it in a document. Then when we would go to create the deliverable, we would review the information in the document and determine what was most important.

We also conducted interviews to collect qualitative data from experts and hobbyists in the field of aquaponics. We held the interviews over Zoom or through email. We first obtained the consent of the interviewee through a consent form, in order to use the information they provided within our project. We then asked questions about their understanding of aquaponics, their credentials, their systems, their teaching advice, and why this topic is a passion that they have pursued. The guide for the interview questions can be found in Appendix A. From this information we gathered facts that aided us in the development of our educational material, design development, blog content and manual content. These interviews expanded our knowledge of aquaponics and impacted how we could make our design accessible to the largest number of people.

3.4 Data Analysis

After collecting information through online resources and interviews, we analyzed the data our team gathered through thematic coding. Thematic coding is the process of identifying different research sources that are linked through a common theme to index the research into categories which establish a framework of themes around the central topic, in this case aquaponics. Our team first reviewed the documents collected as well as the interview transcripts to determine any overarching themes throughout all our research. After we finished reviewing the documents, four major themes arose throughout our research. We then broke up each of these themes in multiple sub-themes with more detail. These themes were then used to guide the development of the deliverables that our team produced for the HSF.

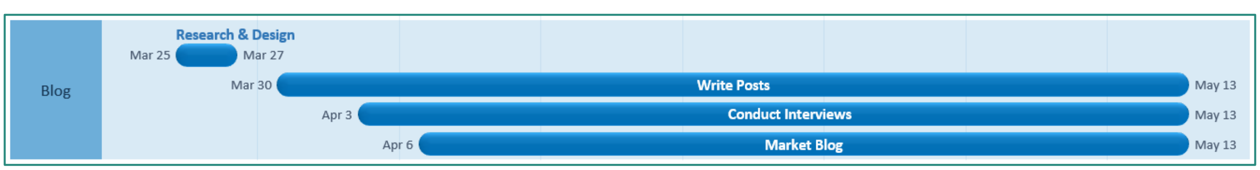
3.5 Deliverables

From our objectives, there were four main deliverables created. These were the blog, the fact sheets and related video, an aquaponics prototype design, and a manual infographic and related video. The following sections will detail how each deliverable was created, using the information found in our data collection and analysis.

3.5.1 Blog

We created a blog as a platform to compile our work and make the knowledge we learned open and accessible to the greatest number of people. The timeline for the creation of the blog can be seen in *Figure 7.* The content for blog posts was developed from the interviews, research that we conducted from literature, and the deliverables of our project. The blog was continuously updated with new information and posts throughout the term as we conducted more interviews and finished each deliverable. We wrote blog posts to share information about aquaponic systems, educational material to guide and teach people about aquaponics, and its benefits as an efficient and compact way of farming. We promoted the blog by sharing the website through our own private social media accounts and a Facebook page dedicated to the blog. We used this to update the public every time a new post was made. This gave us a wide range of readers and allowed them to also share it, creating even more traffic.

Figure 7: Timeline for the blog

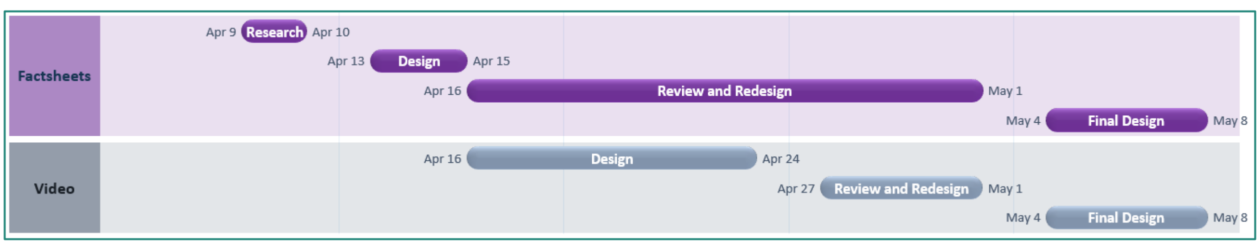


3.5.2 Fact Sheets and Video

We designed three fact sheets and a summary video to educate the Namibian public on aquaponics. Each fact sheet covered a different subject. The first fact sheet was about hydroponics, the second aquaponics, and the third how to build/maintain a hydroponic/aquaponic system. All three fact sheets covered more information regarding the guiding titles and information of food insecurity, drought, and climate change within Namibia. Because the English literacy rate in Namibia is low, a video summarizing the fact sheets was created. This included what hydroponics and aquaponics are, their key differences, and why they are beneficial. To create the fact sheets and video, we followed the iterative design method described in *Figure 6*. We first defined the goal and conducted research on the topics we were suggested to cover and then brainstorm designs. Next, we created a preliminary design, followed by a review and redesign phase. Lastly, we decided upon a finalized design for each material we created. The timeline for this can be found in *Figure 8*. We split up the factsheets and video into two categories. Because the video was based on the fact sheets, it could not be started until the fact sheets were designed. We spent the bulk of the first four weeks conducting research and creating preliminary designs. The final three weeks were dedicated to redesigning.

The goal of the fact sheets and video was to provide rural communities of Namibia with information on aquaponics. To start our research, we first created a list of topics we wanted to focus on for each fact sheet, guided by our sponsors. We then used the information collected through our data analysis to create these materials. We also reviewed the HSF website, thinknamibia.org.na, and took notes on the materials published to get ideas for our design. The next step was to create the preliminary designs of the fact sheets and later the video. We then gave our first drafts to the HSF for feedback. We asked for feedback regarding how visually pleasing they were, their ability to understand them, and how informative they were. Based on the feedback, we redesigned the fact sheets and video. Once data saturation occurred and a finalized design of fact sheets and video had been reached, we provided the HSF with the materials for their use of teaching and publishing.

Figure 8: Timeline for the fact sheets and video



3.5.3 Prototype Design

A working prototype was an instrumental part of our final project. The prototype was intended to be used as an educational tool to teach children in a local school in Namibia about the concept of aquaponics while providing the children with fresh produce once the crops were ready for harvest. The prototype was to serve as a proof of concept for aquaponic growing in small rural communities and can be used to show the ease of making a small-scale system for subsistence use. Due to the COVID-19 pandemic, we were unable to travel to Namibia and will not be able to personally build the prototype. However, we continued to work with the local Namibian aquaponic expert, Burton Julius from the Hanns Seidel Foundation, who will construct the prototype in the school at a later date. To develop the prototype design, we again used the iterative design process. We started by gathering information about what the design should include from Burton. We then brainstormed ideas for the design and created the first draft in SolidWorks. We then received several rounds of feedback from Julius and redesigned the prototype until we reached a final, complete design. The timeline for this can be found in *Figure 9.*

Figure 9: Timeline for prototype and manuals

3.5.4 Manual Infographic and Video

The production of a manual is an essential feature to our project, to allow the prototype design to be built. For a manual, we developed a poster and video. The timeline for constructing the manual is shown in *Figure 9.* The manual development could not be created until the prototype design was finalized. This resulted in a focus on conducting research for manual designs and the development of the prototype design within our first three weeks. We spent the final four weeks developing the manual and revising it.

Again, we followed the iterative design process to develop both the manual infographic and video. In the first stage of the iterative design process we established the need and collected information. The goal of the manual was to explain how to build our prototype aquaponic system we developed for Namibia. Information on agriculture and aquaponics was gathered in our data analysis. For the information on the prototype design, we used the prototype that we designed and reviewed with Julius. The next step was to brainstorm the way in which we wanted to construct the manual. We used our research to determine what we want to include and to ensure that our manual was user friendly and informative. Following the brainstorming stage, our team then decided which design fit our objective the best. We then constructed our preliminary version of the manual infographic and video. We then asked our sponsors for feedback on the usability of the manual, effective portrayal of the information, if it met the needs of the Namibian people, and if there was anything else they believed needed to be changed. We used this feedback to revise the manual infographic and video. This feedback process continued until we reached data saturation and completed the deliverable.

Chapter 4: Findings

While working with the HSF, we gathered information on Namibia, climate change, food security, and aquaponics to develop several deliverables. We conducted research through online sources and interviews with aquaponic farmers. From the information we collected, we produced three fact sheets, a video explaining the fact sheets, an aquaponic system prototype, a manual infographic of the system prototype, a video explaining the prototype and a blog titled "Aquaponic Chronicles." In this section we will discuss our key findings in two sections, the themes of information we collected and the deliverables we created.

4.1 Themes

Throughout our project, we gathered information for our deliverables through online research, interviews, and feedback from our sponsors. Several themes emerged from our analysis of this data. *Table 1* shows the four overarching themes of information we found, Purpose, Economics, Yield, and Design, and their corresponding subsets lie underneath. This section of the findings chapter will explain what we learned about each theme and how we found that information.

Table 2: Breakdown of themes

Purpose	**Economics**	**Yield**	**Design**
Food Security	Investment	Crops	Design Factors
Sustainability	Market	Fish	System Parameters
Commercial/Revenue		Production Time	
Education			

4.1.1 Purpose

The first theme we discovered in our research is purpose. There are many different reasons one may choose to start their own hydroponic or aquaponic system. We found the most common reasons to be food security, sustainability, commercial/revenue use, and education.

4.1.1.1 Food Security

Aquaponics provides a sustainable method of cultivating food which can help improve food security. Food security refers to the state of having reliable access to a sufficient quantity of affordable and nutritious food. From our original project instructions and our preliminary research, we learned about the severity of food insecurity within Namibia and the damaging effects that result from it. Throughout the project, our sponsors recommended we dive even farther into the issue of food security in Namibia, as this was their reason for using aquaponics.

We learned that 430,000 Namibians are food insecure and nearly 70% of Namibia's food is imported from South Africa (BBC News, 2019; Food and Agriculture Organization of the United Nations, 2020). The HSF's aquaponics project hopes to combat food security through hydroponics and aquaponics.

In our interview with Manny Barra from California, he showed us his at home system and spoke about his previous work on aquaponics. While working in the Philippines for the Peace Corps, Barra built his first aquaponics system. His main purpose for this was to provide food security for himself and his fellow colleagues who were living on a low wage. At home, Barra continued his aquaponics system as a method to ensure food security for the future. After experiencing complications with food security in the past, it was an important topic for him and led to a personal investment in aquaponics. Our interview with Barra provided a real-world example of the food security that aquaponic systems can provide to individuals across the globe. This emphasized the necessity for reliable methods of agriculture and the opportunities aquaponics can provide in Namibia.

4.1.1.2 Sustainability

Aquaponic and hydroponic systems provide sustainable methods of agriculture by efficiently using water. From our introductory research we learned about water waste from traditional methods of agriculture being implemented across the world, including popular methods in Namibia (Elkan, 1992). While some countries have easy access to water for agriculture, others struggle to even have access to clean drinking water. In addition to food security, the HSF wanted to implement aquaponics in Namibia as a sustainable agricultural method during their drought. After receiving feedback from the HSF, we were guided towards more specific sources to better understand the significance of climate change in Namibia and specifically the ongoing drought, which was declared a Drought State of Emergency in 2019 (UNICEF, 2019). We conducted further research regarding the Drought State of Emergency, Namibia's Ministry of Forestry, Water and Agriculture, Namibia's Vision 2030, and the United Nations' Sustainable Development Goals to better understand the action being taken to address this issue.

The discussion of sustainability was also a common theme among several of our interviews. When asking individuals what their reason behind starting their system was, most included a comment regarding the environment. Some were looking for an efficient way to grow food at home while others were more aware of chemicals and pesticides and were looking to find a way to reduce chemical usage. In our interview with Paul Mason, he mentioned that he chose to build an aquaponic system rather than a hydroponic system to reduce the amount of added chemicals in his system. Overall, their responses provided us with a variety of sustainable examples of aquaponic systems that influenced our deliverables.

4.1.1.3 Commercial/Revenue

When researching economic advantages to building a hydroponic or aquaponic system, our initial research was targeted towards understanding how much the system would save a consumer. We assumed the major economic advantage would be saving money on produce and fish. We also considered individuals interested in creating commercial systems where they sell most of the crops and fish produced. When speaking to our sponsors, they taught us about various entrepreneurial opportunities for individuals with hydroponic or aquaponic systems, specifically in Namibia. The local aquaponic expert, Burton Julius, explained to us the various applications of these systems and the monetary incentive that could be marketed to individuals in Namibia. Many people within the country may not be interested in growing leafy greens and herbs for their own consumption, however Julius informed us that Namibians should also consider investing in hydroponics or aquaponics to sell these crops at market.

Our interview with Paul Mason also provided our team with further insight to the economic investment that aquaponic systems are. Mason discussed his system with us and explained his future goal of creating a commercial system to sell produce and fish. He was currently working on a smaller scale system in his backyard that would serve as an example for his future plans. Our interview with him allowed us to understand the mindset of profiting from an aquaponic system beyond consuming the food produced.

4.1.1.4 Education

Education is another purpose for the HSF's aquaponics project. The purpose of our work was to provide informational materials to teach Namibians about the benefits of aquaponics and how they can build their own system. As well, the HSF still plans to implement an aquaponics system in a local school to further teach about aquaponics. Through feedback from our sponsors, we further learned the importance of making creative deliverables with Namibia specific information to encourage learning.

When conducting our interviews, we spoke with Jim Rugarber who works as a high school teacher. His class allowed students to learn about aquaponics in a hands-on environment where they were grouped into teams and challenged to build and maintain an aquaponic system over the course of the school year. Jim's advice on teaching and engaging his students in aquaponic learning was insightful for our project. He provided examples of how he allowed them to be creative in their methods of building and encouraged them to work together to solve problems. The information he provided allowed us to better understand the challenges of teaching such a complex topic and helped us create our deliverables. We made sure to include alternative materials and ideas when explaining how to build a system. We also used general terms to encourage readers to find various materials and not feel restricted or limited when building. We emphasized that aquaponic systems are built through trial and error and that there are various ways to be successful.

4.1.2 Economics

The second overarching theme that we developed throughout our project was based on the economics of hydroponic and aquaponic systems. We concluded that along with having a purpose for building a system it is essential for the system to be economically beneficial. This led us to collect information through research, interviews, and conversations with our sponsors, as to how hydroponic and aquaponic systems can be a beneficial investment.

4.1.2.1 Investment

We found that the main economic factors one must consider for a good investment are initial investment costs, market competitiveness, environmental impact, water quality, system complexity and maintenance costs (Danner et al., 2019). When starting a new system, the costs add up quickly and it is necessary to have a return on investment in order to make it a good financial decision. It has been shown that when an aquaponic system goes to market it is common to have a net loss in fish production and a net gain in crop production (Engle, 2017). This means that the fish production does not typically provide a return on investment, whereas the crop production is likely to result in a profit. This draws the conclusion that after initial investment, the average system commonly results in a system that will yield a profit. This was supported when we spoke with Paul Mason. He is starting an aquaponic system as a new economic venture and, with the current market, he saw it as a very profitable direction to bring his career into.

When looking specifically at hydroponics, we found a large economic factor to be, water consumption. Hydroponics greatly reduces water consumption compared to traditional agricultural techniques and allows plants to grow more effectively due to less pests, weeds, and poor water quality (5 reasons hydroponic growing is more profitable than soil growing, 2017). When analyzing which hydroponic system would be the best investment commercially, we concluded that it would be a nutrient film technique system. These systems have the best water conservation, are easier to maintain, and have a lower rate of maintenance issues (Danner et al., 2019). The types of crops grown in the system can also help it to be a good economic investment as well. When talking with Julius and through collecting data for our project, we found that using hydroponic systems to grow fodder for livestock in Namibia is a great economic investment. It allows for continual fresh green fodder for their livestock throughout all seasons, enabling food security for the animals. It also allows for the farmer to be minimally affected by changes in market price when purchasing fodder, which can often be an economic challenge (Brown, 2019). A typical hydroponic system can have its crops harvested as soon as six weeks after planting which is a great cycling time (Storey, 2017). It can result in quick turnover for the farmer allowing for them to produce more crops, and therefore a greater return on investment.

Aquaponic systems also have some key factors as to why they are a good economic investment. The typical aquaponic system can have its crops harvested up to twelve months after the initial planting (Storey, 2017). While this is not a fast crop turn over, an aquaponic system does have many more factors than a hydroponic system and you will also get the additional crop of fish. Another reason aquaponics is a great investment compared to traditional agricultural methods is that it is 95% more water efficient due to the water reuse cycle of the system. It also allows for an organic ecosystem where the farmer can control the chemicals and nutrients that each piece of the system receives. In addition, it is low maintenance, space efficient and a very sustainable option. Along with all these benefits leading to a good investment decision, there are also some drawbacks that we came across. With the use of a pump and the potential need to heat the system, there are often electricity costs. There are also initial set-up costs to build the system and it is typical to have unexpected issues that may cause additional investment into the system. This was highlighted in our interview with Jim Rugarber when he discussed how something as small as buying new fittings due to the system leaking, can quickly add up to a few hundred dollars. Despite these unexpected costs, the benefits of aquaponics make it a good economic investment.

4.1.2.2 Market

It was also important for us to look at the market to conclude if aquaponics and hydroponics were a good economic investment. To do this, we looked at the Compound Annual Growth Rate (CAGR) for both industries. This statistic shows the projected constant rate of return that a farmer could expect in the given time frame. In simple terms, based upon the market, this shows the percentage of profit that a farmer can expect, based upon the initial investment that they put into the agricultural system. The forecast of the following data is for the prediction of years 2020-2025. It was found that hydroponics would have a CAGR 6.8% and aquaponics would have a CAGR 12.5% (Hydroponics market - growth, trends and forecasts, n.d.; Aquaponics market - growth, trends, and forecast, n.d.). This supported our conclusion that these are good agricultural systems to invest in. Not only are they both profitable in the short term, but in the long term, the markets are expanding, and they will continue to be a well-informed investment in future years.

4.1.3 Yield

Compared to traditional agriculture, hydroponics and aquaponics have a higher crop yield. Although not all plants and fish are suitable for these systems, there are still a wide variety that can be used. We determined this through our research into how hydroponics and aquaponics work, feedback from our sponsors, and interviews.

4.1.3.1 Crops

Many crops can be used in a hydroponic or aquaponic system. The main determinants for the types of plants in a system are the climate and the size of the system. Through our online research and interviews, it was reiterated that certain plants can only be grown in specific climates or seasons. For example, Brent Meins had extra grow beds set up to grow melons during the warm summer months and in the winter he uses a greenhouse to grow herbs and vegetables.

In Sydney, Australia, Paul Mason can only grow lettuce in the cooler winter months and instead grows capsicum and zucchini in the hot summer months. Through online research about systems, we learned that the size of the system also determines what plants can grow because small systems have less nutrients for the plants. For small systems, the best plants to grow are leafy greens and herbs. In larger systems, there are enough nutrients to grow many fruits, vegetables, and beans (Wood, 2019).

We found that for Namibia, a hydroponics system can be used for growing livestock fodder and an aquaponics system can be used for leafy greens, vegetables, and herbs that can be consumed or sold at local markets. This information was gathered in our communication and feedback with Burton Julius. He has firsthand knowledge from living in Namibia and believes this set up would be easily accepted by Namibians and provide the most benefit.

4.1.3.2 Fish

The main determinants for what fish are suitable for an aquaponic system are the climate and what one will consume or sell. Through our online research and interviews, we saw how important it was that the fish tank be kept at a warm enough temperature for the fish to remain active. Therefore, it is important to choose a fish that fits your climate or incorporate heating systems to keep the fish actively producing waste. We learned from Julius, that eating fish is not very common in Namibia. It was determined that tilapia or koi would be the best fish for our prototype system because those would be the only kind that Namibians would eat and have easily accessible. However, these are not the only fish commonly used in aquaponics. In our interviews, we spoke with people using bluegill, catfish, silver perch, koi, and tilapia. Hearing that tilapia and koi have worked well in people’s systems across the world solidified that those two fish would be the most viable options for an aquaponics system in Namibia.

4.1.3.3 Production Time

When starting a new system, hydroponics and aquaponics will take varying times to reach full production capacity. A new hydroponics system will only take about six weeks to reach full harvesting capacity because the nutrients are coming straight from the water and are readily available to the plants. However, for a new aquaponics system, you must first cycle the water with ammonia for six weeks before adding fish or plants to the system. This allows the bacteria colonies that will turn the fish waste into nutrients for the plants to grow. From there, it can still take up to a year to reach full harvesting capacity as the fish, plants, and bacteria colonies grow and adjust. Once the systems are at full capacity, crops are harvested approximately every three to four weeks (Storey, 2017). This information was determined through online research and from speaking to Julius, after its importance was noted in the fact sheets feedback.

4.1.4 Design

Before constructing a hydroponics or aquaponics system, one must first settle on the design that best fits their individual needs. There are a variety of factors that must be considered when designing a system from the location it will be built to the type of system that will best suit the needs of the user. Through our group's research, we have determined some of the more important factors and parameters that should be considered when designing a hydroponics or aquaponics system.

4.1.4.1 Design Factors

There are several factors to consider when designing a hydroponic or aquaponic system. The first step is to decide what the purpose of the system is. In our interviews with various aquaponics farmers, we got to learn more about why each individual initially built their system. The reasons ranged from becoming a commercial business to increasing food security for oneself. All farmers must consider their purpose to assist in determining size, crops produced, and the type of system to base the design on. Once the purpose of the system is decided upon, a farmer can then begin to consider the details which will help optimize the system for their needs.

One such detail an aquaponic farmer needs to consider before designing a system is the climate it will be built in. In several of our interviews, such as with Paul Mason, we found climate to be a major consideration when designing a system. Mason told our group that, since his system was built in his backyard in southern Australia, he needed to use a breed of fish that was comfortable in a wide range of temperatures to achieve maximum production. He also said that some plants such as lettuce were not always suitable for his system due to the 40°C summers. This information was especially helpful when considering building a system in Namibia, since we had to consider what kind of crops could grow effectively outdoors in the arid climate. Julius also told us to consider this when constructing our prototype design and manual by informing us the plants would get sun-damaged without shade and the fish that we chose based on the climate, tilapia, would underproduce waste at night when the water temperature drops.

4.1.4.2 System Parameters

After analyzing the design factors, the farmer can find the type of system and materials best suited for their needs. Through our research, we found three prevalent design types that a grower can use in a small scale hydroponic and aquaponic system: Nutrient Film Technique (NFT), Deep Water Culture (DWC), and Media bed, shown in *Figures 2-4* (The surprising benefits and types of aquaponic systems, 2015). In our interviews, we saw one or more of these methods being implemented in the systems. We followed this guideline in designing our prototype and decided, based on conditions that Julius gave our group, to use a Media bed system. We came to this conclusion because it is a relatively simple and inexpensive design to produce and most of the components could be easily found in Namibia.

Once the type of system is determined, the necessary materials can be chosen. For the frame, the material must support the weight of the grow bed at max capacity and not deteriorate in the climate the system is built in. Many systems use wood or metal to build the support structure. For the grow bed and fish tank, these will ideally be made of plastic as it will not degrade over time. To do this, some growers, like interviewee Manny Barra, implemented what is known as the chop and flip method. This method involves cutting an IBC plastic tote in half and using one half as a grow bed and the other as a fish tank. These totes typically have pipe fittings pre-installed, allowing for easier plumbing setup. Based on our research, inexpensive PVC tubing is easily accessible most places and is the most commonly found piping in systems. It is commonly used as both a drainage system as a standpipe or bell siphon and used to transport water from the pump to the grow bed.

All aquaponics systems also need a pump to move water from the fish tank to the grow bed. We learned that the flow rate, fish tank volume, filter volume, and plant growing area will all affect the design of the system. In media bed systems, the type of media for the grow bed must be considered. Through research, we found that the most common media varieties used are expanded clay pellets, lava rock, and any gravel or small rock-based media (Bernstein, 2011). One final consideration when choosing materials, we learned from Julius and our interviewees is whether to have more than one fish tank. Because the adult fish will eat the younger fish if in the same tank, one should consider separating them to avoid having to buy new fingerlings each harvest. This problem can be mitigated by separating the adults and the juveniles either by a fine mesh in a single tank or by using two separate tanks that are connected.

4.2 Deliverables

The purpose of this project was to develop several deliverables for the Hanns Seidel Foundation's aquaponics project. These deliverables were guided by the themes discussed in the first part of this chapter. The deliverables created were:

1. Fact Sheets
2. Video on Fact Sheets
3. Aquaponic System Prototype
4. Manual Infographic
5. Manual Video
6. "Aquaponic Chronicles" Blog

These deliverables can be found on HSF's website, ThinkNamibia.org.na, and will aid in their initiative to bring aquaponics to Namibia.

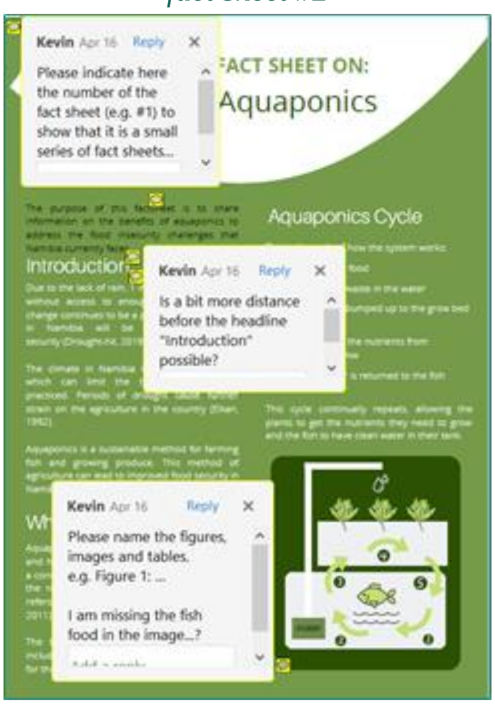
4.2.1 Fact Sheets

To provide educational materials on aquaponics for HSF, three fact sheets were developed. The topics covered were: Hydroponics, Aquaponics, and Building and Maintaining

Hydroponic and Aquaponic Systems. Each fact sheet was created in the A4 size standard and was four pages long. They all followed the same structure, with the introduction on the first page, followed by supporting material and then the conclusion, glossary, and references on the last page. Visually, they contained the same style header, footer, text, and images to provide unity across the fact sheets and show that they are part of one initiative, which can be seen in *Figure 10*.

Figure 10: First page of all three fact sheets

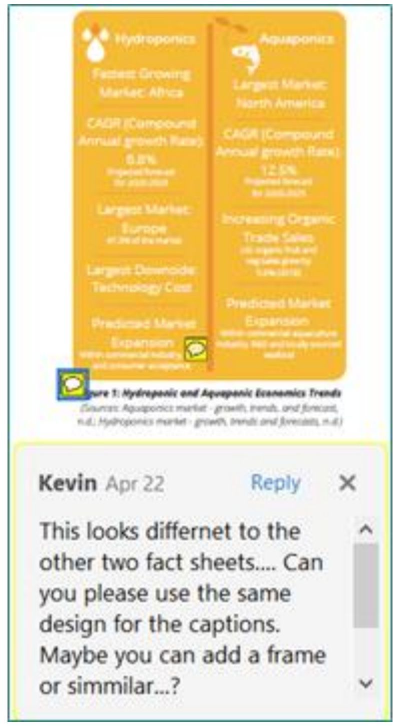
Figure 11: Feedback on first draft of fact sheet #2



The information in the fact sheets covered the themes previously discussed that were determined through online research, feedback from our sponsors, and several interviews. Fact sheet #1 covers information on hydroponics. It details the three different hydroponic techniques, the pros and cons, and yield determinants. Fact sheet #2 covers information on aquaponics. It details how aquaponics works, the pros and cons, and what types of crops and fish you can use in the system. Fact sheet #3 covers information on how to build and maintain aquaponic and hydroponic systems. It details the materials needed, important logistics, economics, yields, major differences between the systems, and future opportunities. All three fact sheets cover important information for Namibia, such as food insecurity, drought, climate change, policies, and the agriculture industry.

Throughout the project, each fact sheet went through several rounds of feedback. Fact sheets #1 and #2 were completed first and sent to our sponsors at HSF for feedback. *Figure 11* shows some of the feedback we received on our first draft. The feedback mainly revolved around the structure and layout of the fact sheets. It was also recommended that we tailor the information more directly towards the Namibian context. Julius provided us with a list of topics for us to cover, such as the current situation in Namibia in terms of food security, drought, economics, and current efforts in Namibia to improve their situation.

Figure 12: Feedback on first draft of fact sheet #3



For the second draft of fact sheets #1 and #2 and the first draft of fact sheet #3, we tried to address all the recommendations given. Again, the feedback included structural and visual changes, but the quantity was much less than the first draft. Most of the comments were to follow the same format across all three fact sheets as seen in *Figure 12*, or to adjust colors for better reading. As well, there was less feedback on the content of the fact sheets. The focus of this feedback was to be consistent with the metric system, the use of % versus percent, and the use of sector versus industry. There were also small changes made to clarify information.

After reviewing all the feedback, another draft of the fact sheets was created and sent for feedback. Our sponsors had no new feedback and it was determined that these would be the final fact sheets, which can be found in Appendix B, C, and D.

4.2.2 Video on Fact Sheets

To further enhance the HSF's ability to share information on aquaponics, we created a video that covered all the information accumulated in the three fact sheets. The aim of this was to be able to reach an audience that may not be able to read the fact sheets or other materials. The video contains an animation with sound, to walk the audience through the content. To keep the video short, we included the most important information from the fact sheets. It covers the current situation in Namibia, how hydroponics and aquaponics can be a solution, pros and cons for each, key differences, and why you should implement both. To understand what the

Figure 13: Video stills from first draft of the fact sheet video

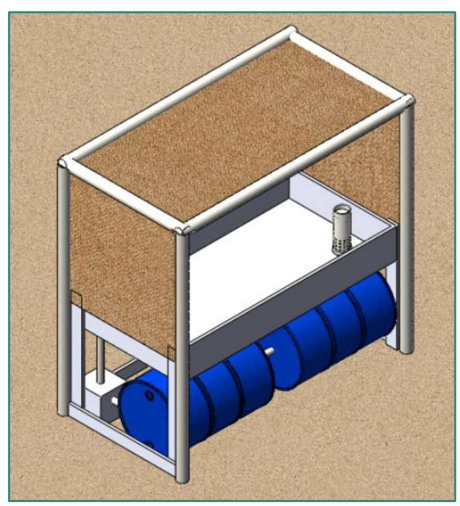
animation looked like, video stills can be found in *Figure 13.* Before recording the final audio, a script was written and sent along with the animated video for feedback.

After receiving feedback, the video and script were updated. It was recommended to make the video more animated and attractive and that a first and last slide with the project logo, contact info, and authors be added. As well, for some of the slides, it was recommended to cut down on the amount of information shown at once. Regarding the content, however, there were not many changes needed. We made edits to the video and corresponding script before recording and attaching the script to the video. Stills from the updated video can be seen in *Figure 14.* After sending the updated draft to our sponsors along with the complete audio, there was no new feedback. The link to the finalized fact sheet video can be found in Appendix F.

Figure 14: Video stills from final draft of the fact sheet video

4.2.3 Aquaponic System Prototype

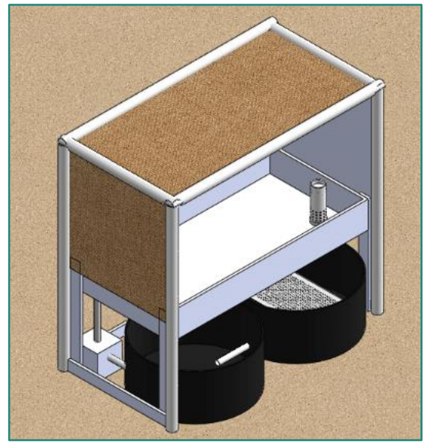
Figure 15: First design of the aquaponic system prototype



We developed a prototype of an aquaponics system that would fit the needs of Namibia. We determined the aspects of the system by considering the suggestions from Burton Julius, our research, and our interviews. The first draft of the design can be seen in *Figure 15.* It included two 200L plastic drums for the fish tanks. One tank holds the adult fish and the second tank is split in half to supply a breeding and juvenile section. A stand for the grow bed is built using a material of choice, however, we recommend PVC pipes. This is because in Namibia metal will quickly rust and wood will be eaten by termites. PVC pipes are a simple and cheap material that can withstand these conditions. The grow bed is then stacked over the drums with this stand. The grow bed was designed to be 1 m by 2 m to allow easy access from all sides. PVC pipes are again used to connect the fish tanks to the water pump, grow bed, and siphon to create the full cycle of the system. Additionally, a 30-40% direct sunlight protection shade netting is recommended to protect the system from pests such as insects, birds, and small mammals. A greenhouse and a donkey heating system is also recommended to be added to the system. This allows the system to be kept at a suitable temperature in the colder months.

This design was sent to Julius, who has an extensive background in aquaponics and lives in Namibia, for feedback. The only suggestion was to replace the 200L drums with round plastic molds, like one of his previous designs. This was because the 200L drums would not be easily accessible in Namibia. Our finalized design can be seen in *Figure 16* and Appendix F.

Figure 16: Final design of the aquaponic system prototype



4.2.4 Manual Infographic

An infographic was developed to serve as a construction manual for the aquaponic system prototype. We started the manual with information on why an aquaponics system would be beneficial. A list of materials that can be easily obtained and used for the system is given. The steps for building the system are described with corresponding images of the CAD drawing, shown in *Figure 17*. Lastly, there is a post construction section that details the next steps and suggests viewing our fact sheets to find more information.

After receiving feedback from our sponsors, several changes were made to the manual. First, the materials list, images, and steps for building had to be updated based on the updated version of the prototype design. The size of the infographic was also adjusted, to fit the A2 size. It was also recommended to shorten the amount of text on the infographic, allowing font size to be increased and more spacing between sections. To do this, we removed any information that was unnecessary to the understanding of the prototype. Lastly, the photo at the top was switched to something that will be more recognizable. You can see in *Figure 18*, we added two new photos. These photos provide a better image of aquaponic systems and can be more recognizable to the average Namibian. The final draft of the infographic can be found in Appendix E.

Figure 17: Images on infographic showing to show construction steps

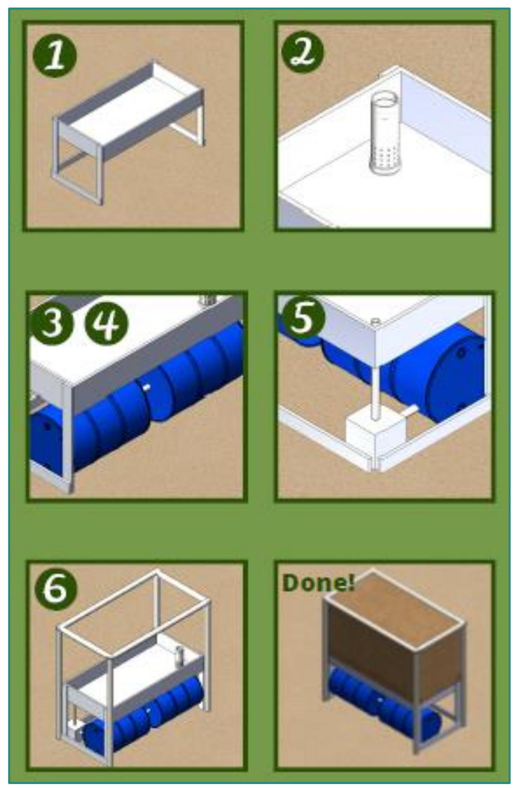
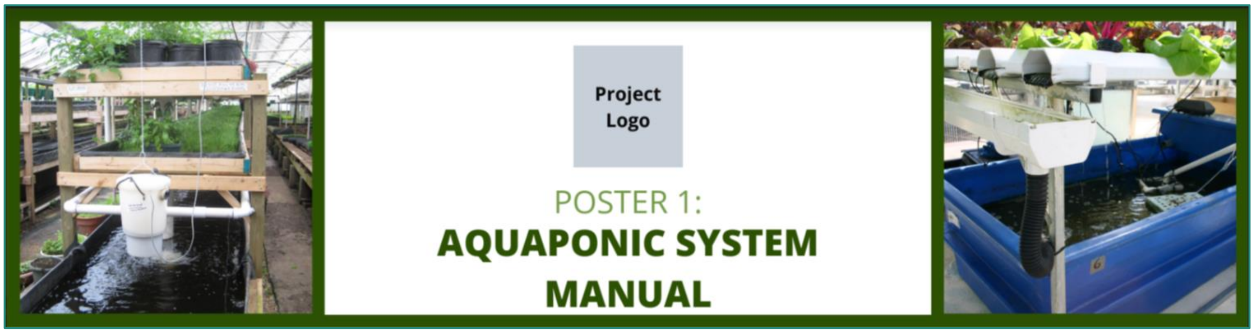


Figure 18: Updated images on final manual infographic

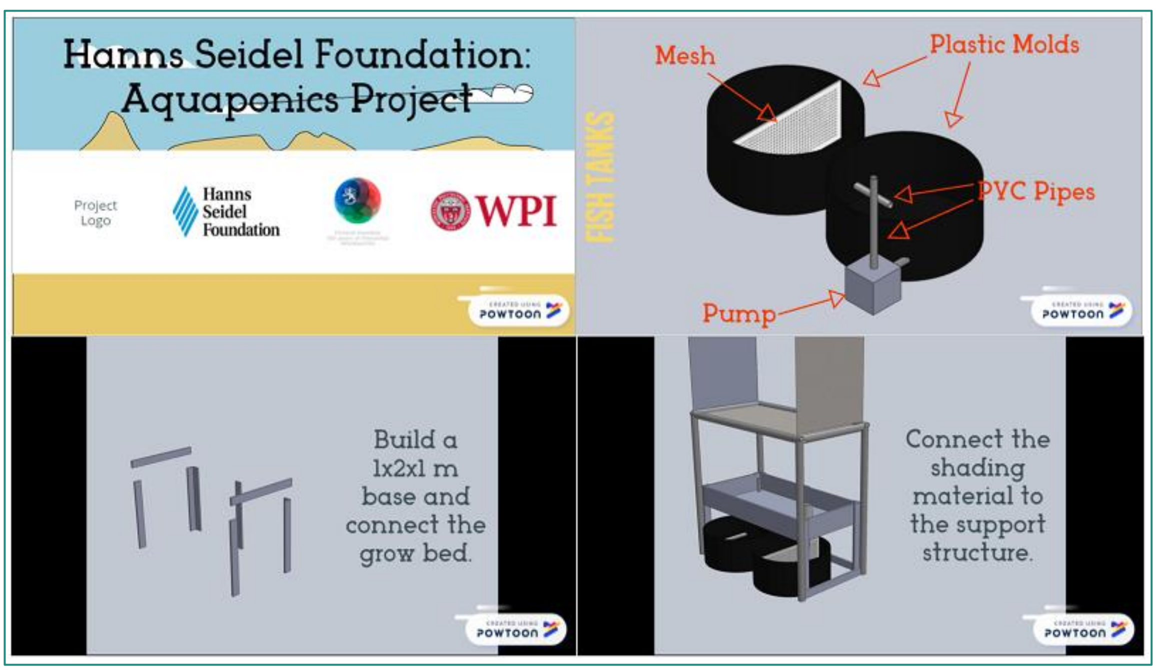


4.2.5 Manual Video

A manual video was created as another way to show how to construct the aquaponic system prototype. This visual representation of its construction provides a better understanding on how to build the system. The video began by detailing the parts of the system and the materials required. Then, we used the CAD design to create a video showing all the pieces coming together. The steps were then written out as the pieces were put together in the video. Again, the video was narrated with audio for better understanding.

The first draft was this video was sent to our sponsors for feedback. The only comments were to adjust the colors so there was a better contrast. The video was updated and again sent for feedback. There was no new feedback on the video, and this became our finalized draft. Video stills of the manual video can be seen in *Figure 19.* The link to the final video can be found in Appendix F.

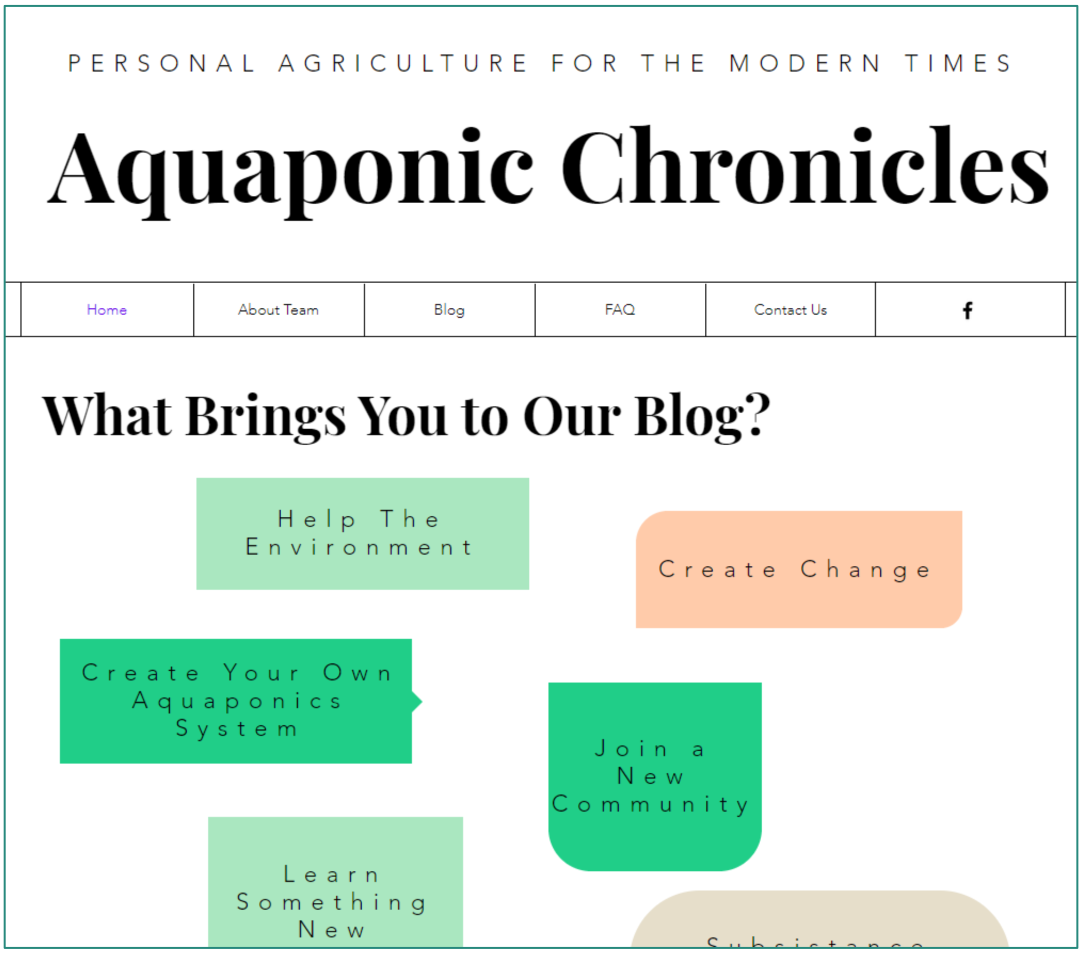
Figure 19: Video stills from final manual video



4.2.6 "Aquaponic Chronicles" Blog

We created a blog called "Aquaponic Chronicles" to share information about aquaponics with people from all over the world. This was not part of our original project deliverables, but we saw an opportunity to share information due to so many people learning online during the pandemic. The homepage of the blog, shown in *Figure 20*, introduces the purpose of the site, what aquaponics is, and our most recent posts. The top of the homepage has links to the different pages, "Home," "About Team," "Blog," "FAQ," and "Contact Us" along with a link to our Facebook page for marketing the blog.

Figure 20: Homepage of blog

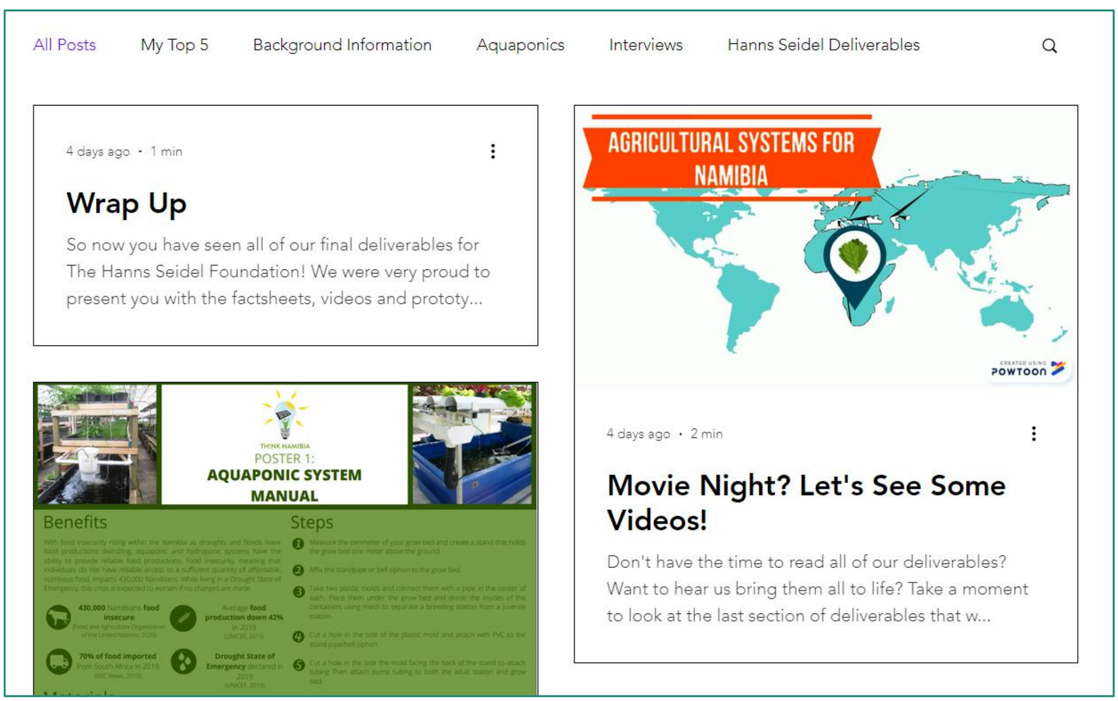


The "About Team" page introduces who we are and our purpose for the blog. It explains the Interactive Qualifying Project (IQP) and who the Hanns Seidel foundation is. As well, there are links to learn more about the IQP requirement at WPI and our sponsors the HSF.

The “Blog” page contains all the blog posts we have written. You can see in *Figure 22*, that the posts can be filtered by “All Posts,” “My Top 5,” “Background Information,” “Aquaponics,” “Interviews,” and “Hanns Seidel Deliverables.” There is also a search bar to easily find posts. The blog posts written contained information on what aquaponics is, why it is beneficial, what our project is, and overviews of the interviews we conducted. An example blog post is shown in *Figure 21*, where we interviewed Brent Meins and wrote about his aquaponics system. The next page on the blog is the “FAQ.” These are answers to frequently asked questions about aquaponics to provide clarification for our viewers. And the last page, “Contact Us,” takes the user to a form to send us a message. The link to the blog can be found in Appendix F.

Figure 21: Example section of blog post

Figure 22: Blog section



Chapter 5: Discussion

Throughout our project, we have learned a tremendous amount about aquaponics and how it can solve issues Namibia is currently facing. However, this did not come without several problems we had to overcome. While facing these challenges and developing our project, we have been able to come up with recommendations for how the HSF can further the Aquaponics Project. This section will address the problems we faced, describe our recommendations to the HSF, and explain the future implications of our work.

5.1 Challenges

Throughout our project work, our team faced many problems. One major difficulty was the travel restriction due to the COVID-19 pandemic, which resulted in us not being able to travel to Namibia. While this was a big challenge, we moved forward with our project and continued to work with the Hanns Seidel Foundation remotely from the United States. This then led to us facing communication issues from working at home with a six-hour time difference between us and our sponsors. However, our team was able to work around these challenges and adapted our project. One adaptation was to create a blog with online teaching resources. We were able to implement more online tools and resources, such as interviews with aquaponic experts and hobbyists through video calls and emails.

Another difficulty we faced due to COVID-19 was that we could no longer build an aquaponics prototype system in a rural Namibian school. This also impacted our ability to make a design manual based on the prototype system we were to build. To overcome this, Julius, who lives in Windhoek, plans to move forward with building the prototype in the school once it reopens. We adapted this portion of the project to include us designing a prototype that could be built by any individual. We then produced a video and infographic using computer aided design visuals to serve as a manual for anyone wishing to build the prototype system.

Despite the distance between us and our sponsors, we were able to remain in constant contact throughout the project. The use of email and Zoom allowed us to easily contact each other and stay involved in the project. These tools helped us to find solutions to many of the problems we faced.

5.2 Future Recommendations

As the HSF continues their project of teaching and building aquaponic systems in Namibia, we have several recommendations for their future work. When planning to travel to Namibia and interact with young students, we spoke with a teacher about how to engage students in lessons. The main takeaway was that the lessons should include games and interactive elements. Therefore, we recommend to the HSF that students have hands-on experience, so they are more likely to be engaged in what they are learning. This can be done by having the students help build the aquaponics system and later harvest the crops. Another suggestion for teaching would be to challenge the students to be creative within their aquaponic systems and learn from their mistakes. A way to do this with aquaponics would be to include several different components to their system. For instance, a nutrient film system, media bed system, and a deep water culture system could all be included in their aquaponic designs. This will help the students better understand the various methods of building an aquaponic system and give them the ability to create a unique system.

For the fact sheets, manual, and videos, we recommend that the HSF include these within their lesson plans while at the school. They have a plethora of information that could be adapted to the learning level of the students to teach them about food insecurity, climate change, and aquaponics. We also recommend that these documents are made easily accessible to and be advertised to members of the community who are interested in learning more about aquaponics to improve food security.

We also recommend that our deliverables be implemented outside of Namibia to promote sustainable methods of agriculture in other countries. Seeing as the HSF is a global foundation with over 70 project cites, the materials we produced can be tailored for different regions across the globe. The deliverables should be edited to fit the needs of the country and be implemented within their area to further provide information about aquaponics. This would allow for sustainable agricultural methods to be implemented in other food insecure regions.

Finally, we recommend that the HSF implement the prototype aquaponics design when building their intended aquaponic system in the local Namibian school. We designed a very simple small-scale system that can be easily modified to a larger scale if necessary. We hope that the HSF can benefit from this design when they begin building the larger system in the school and are able to use it to advertise home units to individual members of the community.

5.3 Future Implications

In the future, we are excited to see the work that the HSF will achieve in Namibia using the materials we developed in this project. Due to COVID-19, parts of the HSF's Aquaponics Project were put on hold. Once it is safe to do so, the HSF will continue with their plans to teach and build an aquaponic system in a local Namibian school. This will allow young students to learn more about sustainability, food security, and agriculture. It will also expose students to information regarding hydroponic and aquaponic systems and the process of building and maintaining a system.

The deliverables we have created will help Namibia learn more about aquaponics and how they can build a system to improve their food security. The fact sheets, videos, and infographic will all be shared on the ThinkNamibia website to provide easy access for community members. Our videos especially will provide an easy method of sharing the information for those who are unable to read or with varying educational levels. The fact sheets will allow Namibians to learn about food security, climate change, and aquaponics. The manual and construction video will then be a guide for individuals to build their own systems.

Although we were not able to work with the HSF as they build the prototype aquaponics system, we were able to continue our work with them remotely and provide them with tools to teach individuals about sustainable methods of agriculture. In the future, these materials have the ability to provide tools for anyone to improve their own food security.

Chapter 6: Conclusion

At the conclusion of our project, our team was able to deliver three fact sheets, two videos, a prototype aquaponics design, and one manual infographic to the HSF in Namibia. The topics of the three fact sheets were: hydroponics, aquaponics, and maintaining and building an aquaponic and hydroponic system. We then created an instructional video which highlighted the key information from the fact sheets. The prototype design was created to be a small-scale system for Namibia. With the design, we produced a manual infographic and video of how to build the system.

In addition to the HSF deliverables, we created a blog. We used the blog as a platform to inform the public on the benefits of aquaponic systems. The blog contains educational information, overviews of interviews we conducted, and the HSF deliverables. The blog will be highlighted on Hann Seidel's Think Namibia website to provide resources for education on aquaponics.

Through the deliverables our team produced, we were able to conclude four common themes. These themes were purpose, economics, yield, and design. For purpose, we learned about the many different reasons people choose to use aquaponics, which include food security, sustainability, revenue, and education. Economics plays another role in aquaponics, where people must consider their investments and the market to determine if they will profit from the system. With yield, many factors such as climate and size of the system will determine which crops and fish should be used. As well, hydroponics and aquaponics have different production rates which can play a part in deciding which type of agriculture to use. And for the design, the design factors and system parameters are greatly impacted by climate, purpose, system size, and materials available. These themes that arose guided our understanding of hydroponics and aquaponics and impacted how we shared the information in our deliverables.

With the deliverables we developed, HSF will continue to educate the community about aquaponics and build the prototype in a local school. We have concluded several recommendations as they move forward. We recommend that the foundation encourages the students to be creative within the building and maintaining of their system and provide them with lessons to gain hands on experience and interact with their learning. We also recommend that the prototype be adapted and scaled based on the needs of the community to further improve food security. Lastly, we recommend that the HSF adapt and implement our deliverables in their other global sites to further educate communities on sustainable methods of agriculture.

We hope that the work we have created over the past several weeks will benefit the HSF's Aquaponics Project. We look forward to hearing the impact our work will have on communities in Namibia. Although we were unable to travel to Namibia, we are hopeful that our work will positively impact the people living there and encourage them to build aquaponic systems.

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Appendices

Appendix A: Interview Guide

1) Can we share the information you provide with the public through our project?
   a) Would you like to be named or remain anonymous?
   b) Could we include a video of your system on our blog?
2) Can you send us a video of your aquaponics system?
3) Can you tell us about your project?
   a) What are some challenges you faced in setting up your system?
   b) What components of your system were the most successful?
   c) Did you make your system alone or with other people?
   d) What is the scale of your project?
   e) How long have you had this system?
4) How did you decide on what materials to use in your design?
   a) Did your climate impact this?
   b) Did your resources impact this?
   c) Did you have a budget for this project?
5) What plants/ fish do you have in your system?
   a) How often do you eat the products of your system?
   b) Do the seasons affect what you grow?
6) What was your reasoning behind making your system?
   a) Is it a hobby or a means of agriculture for yourself?
   b) Was it to become more environmentally conscious or because of climate change?
7) How did you learn about aquaponics and become interested in the topic?
   a) How much experience do you have with aquaponics? (expert, intermediate, beginner?)

Appendix B: Fact Sheet #1

#1

Project Logo

FACT SHEET ON:

Hydroponics

Water is not a plentiful resource in Namibia. With the use of hydroponics, Namibia would be able to optimize their food production and limit the amount of water consumed. It could result in higher food security as well as growth within the agricultural sector of the economy in terms of livestock feed or other products. The purpose of this fact sheet is to share information on hydroponics and why it is a practice that can benefit the agricultural industry in Namibia.

"Hydroponics is a method for cultivating plants without soil, using only water and chemical nutrients." - Sylvia Bernstein (Bernstein, 2011)

Introduction

Hydroponics is the growth of plants without soil, achieved through a non-soil media and nutrient rich water mixture to encourage plant growth. It is a form of climate-smart agriculture that can provide a sustainable method for obtaining food security in the face of climate change. Hydroponics relies on reusing the same nutrient water for many cycles to minimize excess water usage while also potentially increasing crop yields.

A major benefit of hydroponic systems come from its water efficiency compared to traditional methods for growing crops, making it especially useful for agriculture in arid regions. Several countries around the world have been using hydroponics as a way to get around low rainfall and natural water reserves, with countries in the Middle East setting up hydroponic complexes combined with desalination units to meet local needs for food and water (Stauffer, 2006). This water efficiency comes from the fact that most of the water remains in the system and is recycled. Namibia is another country greatly impacted by limited water resources. In 2019, Namibia entered a Drought State of Emergency where nearly 556,000 individuals are expected to be impacted by a lack of water (UNICEF, 2019). Hydroponics systems provide an additional method of agriculture that is not as dependent on water inputs and can increase production. Sustainable systems such as this have the potential to greatly improve food security within the country as access to water becomes more challenging.

Figure 1: A-Frame NFT Hydroponic System
(Source: Build an efficient A-frame hydroponic system, 2017)

Hydroponic Systems

Nutrient Film Technique System

A Nutrient Film Technique System is a very common hydroponic technique for growing different types of greens. The system is typically made of a long piece of enclosed tubing with a pump that allows water to flow through it and holes cut in the top of the enclosed tubing. Small baskets with grow media are placed into the holes and this is where the plants will grow. They will be suspended above the water with their roots growing downward into the water as it flows through the pipe. The nutrient rich water will flow through the roots of each plant, providing them with their necessary nutrients. This system allows for the plants to have their ideal climate along with access to enough moisture and oxygen. Important factors to consider are the depth of the water, the flow rate and the slope of the system. This system is great because they are quite minimal and are very easy to control ((N.F.T. (nutrient film technique) system, n.d.).

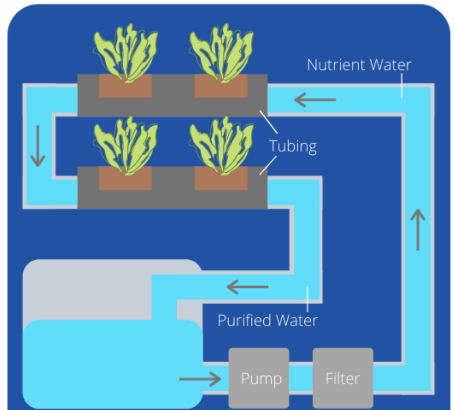

Figure 2: Nutrient Film Technique System

Deep Water Culture System

A Deep Water Culture System is a great and simple hydroponic system that provides plants with the necessary oxygen, water and nutrients to grow. All that is needed is a deep reservoir/container, an air pump, an air stone, tubing, net pots, growing media and hydroponic nutrients. The nutrients are mixed into the water and the deep reservoir/container is filled. The pump is connected with tubing to the airstone which sits at the bottom of the container. The net pots with growth media are then placed at the top of the container with the plants. Once the plants germinate, their roots will extend downward into the water and grow, getting their necessary nutrients from the water. The roots will be submerged 24/7. The air stone and air pump will allow for the water to be properly oxygenated for plant growth. This system will allow plants to grow twice as fast as they would if grown in soil and are quite simple to construct with very low maintenance ((DWC): What is it and how to get started, 2019).

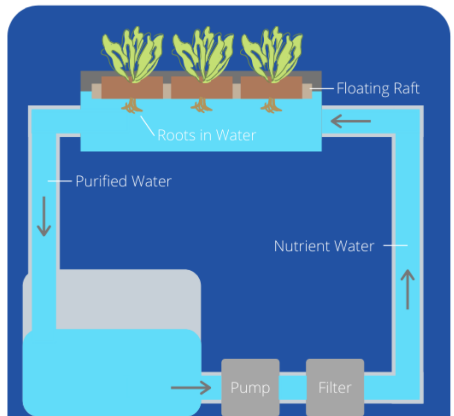

Figure 3: Deep Water Culture System

Media Bed System

It is important to consider the location of the system with media beds because it will be largely affected by temperature, climate and light. Within this hydroponic system, the plants will be grown in media beds. These beds are typically a plastic, leak-proof box that can either be constructed or bought. The bed should be filled with growing media that allows for proper drainage, airspace and water holding capability. There are many different types of growth media to choose from that will depend on the amount of money one is willing to spend. The plants will be placed into the grow media within the beds. There is tubing on one end of the bed, attached to a pump that will fill the media bed with water until just below the top of the media. There is typically a net riser with a grate, to prevent media from interfering, that determines the water level and allows drainage of excess water back into the water source. This will control the amount of available nutrients to the plants. The water will be pumped through the system and provide the plants with their necessary nutrients. The size and depth of the media bed will depend on the type of plant that is being grown and the price point of the system (Hydroponic grow bed setup, n.d.).

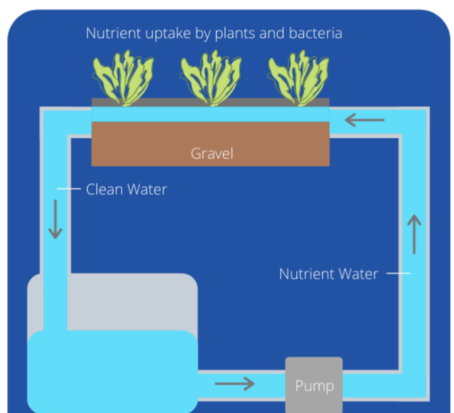

Figure 4: Media Bed System

Hydroponic Yield Determinants

The crop yield of a hydroponics system is determined by a variety of factors that all must be accounted for to make a system maximize it's yield. We must first go back to the principle regarding what all plants need to grow: water, light, aeration, and nutrients.

Water: Water is essential and can be found in abundance in hydroponic systems as it is constantly cycling through the system. One thing to consider with water is filtration as, over time, minerals and other small solids can build up and clog the piping or pump, thus it is highly recommended to include some form of fine filtration to minimize this.

Light: Plants require a substantial amount of light throughout the day and for a specific time depending on the plant. In some areas of the world, this does not come naturally. This can be easily supplemented through the use of grow lighting in a greenhouse for hydroponics. Therefore, hydroponics can allow growing in areas where it would traditionally be difficult to get enough light for large crops.

Aeration: This is oxygen flow to the root systems. As in many of the designs shown above, the roots are constantly submerged in water so air becomes an important component to consider. Many systems will either have all the water discharge from the grow beds for a few minutes per cycle or use air stones which actively release dissolved oxygen into the water over time.

Nutrients: Many hydroponic mixes can be found online though some do miss out on several micronutrients plants require to grow well. To solve this, hydroponic farmers can use the Mittleider Method which involves mixing soil into your nutrient fluid to try and gain some of the more minute particles that aren't typically mixed into the fluid (Stauffer, 2006).

Food Security

Countries around the world are facing devastating challenges due to changing climates. Countries such as Namibia are greatly impacted by dry periods and severe droughts. In 2019 the Ministry of Agriculture reported that due to the ongoing drought, there was a drop in the average harvest production by 42% (UNICEF, 2019). As a result of this drop in production, nearly 18% of Namibia's population is critically food insecure, meaning that there is not a reliable access to a sufficient quantity of affordable and nutritious food. With the unemployment rate within the country at 34%, it is unrealistic for most of the population to be able to afford imported food from South Africa when their crops suffer (Central Intelligence Agency, 2020).

Food insecurity is currently being addressed in a variety of ways such as Namibia Vision 2030, Namibia's Climate Change Policy, the United Nations Sustainable Development Goals, and through Namibia's Ministry of Agriculture. Hydroponics is a sustainable tool that can be implemented within ongoing programs working to make Namibia's population food secure. It provides a resourceful method of agriculture to reduce water usage as well as increase food production. When implemented in addition to traditional agriculture there is an opportunity for communities to become food secure and therefore less reliant on imported food.

Pros and Cons of Hydroponics

Pros	Cons
Hydroponics Systems allow for higher yield	Water must be occasionally changed
Allows for growing in traditionally non-arable climates	Temperature and nutrient content of the water must be checked
Allows growing of plants not native to the region	Certain plants are incompatible with certain systems
Productive from small to commercial scale	
Allows for a much faster harvest period	

Conclusion

Namibia's agricultural system could benefit highly from using hydroponic systems. They greatly reduce water consumption compared to typical soil-growing agricultural techniques. Hydroponics also allows for plants to grow more effectively, with less pests, weeds and lack of nutrients or water, getting in their way (5 reasons hydroponic growing is more profitable than soil growing, 2017). They would also allow for Namibia to grow foods that otherwise wouldn't be abundant in their region. Currently, Namibia relies on South Africa for nearly 70% of their food. By implementing additional agriculture practices, there is great potential for Namibia to reduce this number (BBC News, 2019). This would allow for Namibians to have a more diversified diet with affordable options. All of this could greatly impact the nearly 430,000 individuals currently suffering from food insecurity in Namibia (Food and Agriculture Organization of the United Nations, 2020).

Glossary

Nutrients
Refers to the vitamins and minerals that plants need in order to sustain life and grow.

Cultivations
Refers to the act of caring for a plant in order to aid in its growth.

Airstone
Refers to a porous stone that diffuses large air bubbles into the water of the system. Aerating the water and allowing the plants to receive oxygen.

Food Security
The state of having reliable access to a sufficient quantity of affordable, nutritious food.

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Project Logo

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Appendix C: Fact Sheet #2

#2

Project Logo

FACT SHEET ON:

Aquaponics

The purpose of this fact sheet is to share information on the benefits of aquaponics to address the food insecurity challenges that Namibia currently faces.

Introduction

Namibia has a very arid and dry climate, which limits the types of crops grown in the country. Further strain has been put on the agriculture industry by climate change (Elkan, 1992). Namibia has been facing a very long drought, the worst in many decades. In May 2019, President Dr. Hage Geingob declared a Drought State of Emergency due to the drought conditions in the country. It was estimated that some 556,000 people will be affected by this drought (UNICEF, 2019). As well, the effects of this drought is causing Namibia to become very dependent on food imports. As climate change continues to impact Namibian agriculture in the form of droughts and flooding, food security is at a great risk (Goddek & Keesman, 2017).

To improve food security in Namibia in the face of climate change, new and innovative agriculture practices are needed. One practice that could help is aquaponics, a sustainable method for farming fish and growing produce. This method of agriculture can work to supplement the diets of many Namibians and provide an opportunity to sell crops by providing them with protein, vegetables and starches (Goddek & Keesman, 2017).

What is Aquaponics?

Aquaponics is the combination of aquaculture and hydroponics to produce fish and plants in a constructed ecosystem.

Aquaculture refers to the raising of fish in tanks and hydroponics refers to growing plants in water (Bernstein, 2011). The basic setup of an aquaponics system includes a fish tank connected to a grow bed for the plants.

Aquaponics Cycle

This is the cycle of how the system works:

1. The fish eat the food
2. The fish create waste in the water
3. The waste water gets pumped up to the grow bed with the plants
4. The plants take the nutrients from the waster water to grow
5. The clean water is returned to the fish tank

This cycle continually repeats, allowing the plants to get the nutrients they need to grow and the fish to have clean water in their tank.

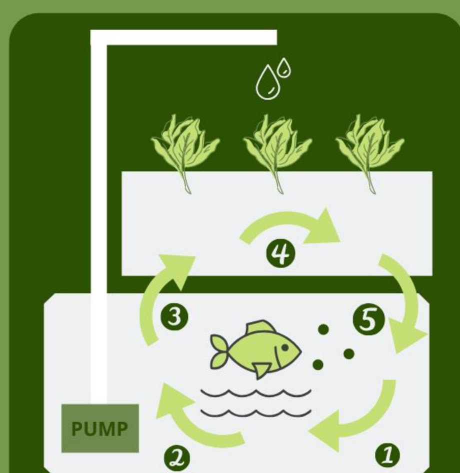

Figure 1: Aquaponics Cycle

Action Taken in Namibia

Climate change has had a huge impact on agriculture in Namibia. Rain-fed agriculture produces the bulk of the world's food yet is the most susceptible to climate change, greatly affecting food security. Namibia's Climate Change Policy strives to protect this vulnerable industry by achieving sustainable agricultural production. This is done through several steps, such as promoting highly adaptive breeds of livestock and crop cultivars, promoting conservation agriculture and ecologically compatible cropping systems, and promoting agricultural production to best maintain and improve household income (Ministry of Environment & Tourism, 2011). These steps will also help Namibia develop climate-smart agriculture (CSA) as promoted by the Food and Agriculture Organization of the United Nations. CSA aims for agricultural methods that can provide sustainable food security in the face of climate change (Food and Agriculture Organization of the United Nations, 2020). Every Namibian can help work towards sustainable agricultural production, by implementing CSA systems like hydroponics and aquaponics.

Advantages

- **Water Efficient:** Aquaponics is much more water efficient than traditional agriculture methods, with 95% of the water put in being reused.
- **Organic Ecosystem:** Aquaponics creates a closed system that balances the nutrients naturally. No chemicals or fertilizers are needed to maintain an aquaponics system. The nutrients come from the fish waste and then are used up by the plants.
- **Low Maintenance:** The main maintenance involved in aquaponics is feeding the fish everyday. There is no need to clean or change the water or add fertilizers to the system.
- **Space Efficient:** Aquaponic systems can be adapted to fit almost any space by growing plants vertically or horizontally or stacking them on top of the fish tank.
- **Sustainable:** Aquaponics is an extremely sustainable way to grow food. It is very water efficient and, because there is no need for soil, it is suitable for dry areas without much water or nutrient rich soils. There is also very little waste produced. Any waste can be used as a fertilizer for soil-based agriculture, put in a compost pile, or if it is unharvested food it can be fed to the fish (Bishakha, 2020; Woods, 2019).

Disadvantages

- **Limitations:** Not everything can be grown through aquaponics. It is difficult to grow large crops that require many nutrients and root vegetables that need to grow in soil.
- **Set-Up Costs:** Aquaponics can be costly to set up. You must purchase parts and materials for the system, fish, and plant seeds. However, some of these costs can be reduced by reusing old materials to create your system.
- **Electricity Consumption:** The water pump for the system must run all day which can lead to high electricity costs. This can be minimized by using renewable sources such as wind or solar power. As well, the fish tank must be kept at a certain temperature. To avoid having to heat the water, you can use a greenhouse for heating.
- **Unexpected Issues:** As with starting anything new, you may run into issues. Aquaponics is more complex than traditional agriculture because you must take care of the fish and the plants. If one part of the system is not happy, the whole system will fail. It can also be difficult to balance the nutrients of a new system, which can harm the fish and the plants (Bishakha, 2020).

Fish & Crops

Aquaponics is best suited for growing leafy greens, herbs, fruits, and vegetables. Depending on the size of your system, different types of plants will grow better. This is because the larger your system is and the more fish you have, more nutrients will be produced for the plants to use. Certain plants require a higher amount of nutrients to properly grow. Some common plants that work well for small systems that produce less nutrients are lettuce, kale, spinach, mint, basil, watercress, and many other herbs. Some common plants that work well for large systems that produce more nutrients are strawberries, melons, tomatoes, peppers, cucumbers, and beans (Wood, 2019).

In an aquaponics system, there are several different types of fish you can use. However, you want to use a fish that will provide enough nutrients to the water and can also be added into your diet. The best types of fish for Namibians to use would be tilapia or koi. Tilapia provides a cheaper option compared to koi, but either can be used based on what you are more likely to consume. Fish farms in Namibia provide easy access to these fish, that can be easily bought from local markets.

Hydroponics

Aquaponics differs from hydroponics because it adds in the benefits of aquaculture.

In hydroponics, plants are grown without soil. The plants are grown in a growing media, such as gravel or clay balls, with water flowing through. The disadvantages of just hydroponics is that expensive nutrients must be put in the water and that the water must be periodically replaced to avoid buildups.

By combining hydroponics with the production of fish, aquaculture, you can solve many of these problems.

Many of the disadvantages in hydroponics and aquaculture are overcome when you combine them and use aquaponics. This is because in aquaponics, you create a self-sustaining ecosystem. This means you do not need to add chemical nutrients to the water and rarely have to replace the water. The system works together to maintain itself (Bernstein, 2011; Stauffer, 2006).

Figure 2: Leafy Greens in a Hydroponic System

Conclusion

Aquaponics provides Namibians with a sustainable and climate smart method of agriculture to implement as a tool in addition to their current methods of agriculture. Floods and droughts have severe impacts on traditional methods of agriculture. With food insecurity predicted to worsen due to the impact of climate change, there is a great need for sustainable agriculture such as aquaponics.

The opportunity aquaponics provides to supplement current diets will work to address food insecurity within the country.

Glossary

Aquaculture
Aquaculture is the method of cultivation for aquatic animals and plants in a natural or controlled environment (Bernstein, 2011).

Aquaponics
Aquaponics refers to a system where fish and plants are grown together. Fish waste in the water produces nutrients for the plants and the plants use the nutrients and provide clean, filtered water for the fish (Bernstein, 2011).

Ecosystem
An ecosystem refers to interaction of a community of organisms with their environment. When talking about aquaponics, this forms an ecosystem of fish, plants, and bacteria (Bernstein, 2011).

Food Security
Having reliable access to a sufficient and healthy quantity of food (Government of the Republic of Namibia, 2004).

Hydroponics
Hydroponics is a method of growing plants without any soil. The plants are placed in grow beds and use only water and chemical nutrients (Bernstein, 2011).

Sustainability
Sustainability in this context refers to the ability of aquaponics to protect and restore the environment, rather than harm it (Bernstein, 2011).

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Project Logo

Appendix D: Fact Sheet #3

#3

Project Logo

FACT SHEET ON:

Building & Maintaining Aquaponic & Hydroponic Systems

The purpose of this fact sheet is to share information on building and maintaining hydroponic and aquaponic systems. This includes materials, economics and yield potential.

Introduction

Namibia has been facing challenges of climate change throughout the past several years. Droughts and floods have had a harsh effect on the agriculture in the country.

These extreme weather conditions have caused crop cultivation to fail and left poor grazing conditions for cattle. In 2019, it was reported that Namibia had its driest year in 90 years. If these poor weather conditions continue to persist, the food security in the country will continue to worsen. It is important to take steps towards climate smart agriculture to improve food security (Namibia's devastating drought: Our strategy so far, 2019).

When used alongside other agriculture methods, hydroponics and aquaponics can greatly improve food security. These methods provide sustainable ways to produce crops, fish, and livestock fodder. Hydroponics and aquaponics do have some differences, but implementing either or both systems can provide many benefits.

Materials

Here is a general list of items that are useful when beginning your hydroponic or aquaponic system. The container for fish is not required in a hydroponic system. Most of these items can be purchased at a general hardware store.

Water Pump:
This is to move water throughout the system.

Aerator:
This provides oxygen to fish and plants.

Large Container for Fish (Aquaponics):
A common tank is an IBC tote or any large plastic tub or bucket.

Grow Bed:
This holds the growing material and crops. IBC totes or any large bin can be used. PVC pipe can also be implemented by drilling holes for growing pots.

Growing Pots:
Small pots will hold each individual plant. Small pots can be purchased or the tops of plastic water bottles can be used.

Grow Material:
This material surrounds the growing pots and allows a surface for bacterial to grow on. These can be clay pebbles, river rock, or lava rock.

PVC Pipe:
A 7.5 cm pipe is typically sufficient to move water through a system.

Water Testing Kit:
This is to test levels of pH, ammonia, nitrite, and nitrate in your system to ensure the plants and fish have a suitable environment.

Support System:
Wood, metal, or concrete can be used. Wood and metal will deteriorate and rust over time and require more maintenance

Cover:
This is to protect crops from insects and animals. A thin covering that allows light through will be necessary.

(Brooke, n.d.)

Logistics

When starting your own hydroponics or aquaponics system, there are some important logistics you should consider. First, you want to choose an area that has a stable and level ground to avoid the legs from sinking into the ground, which causes disrupted water flow, flooding, or collapse. You must also consider weather conditions and animals in the area. Heavy winds, strong sunlight, insects, birds or small mammals, can damage the plants. A 30-40% direct sunlight protection shade netting can be used to enclose and protect the entire system. The use of a greenhouse and a donkey for heat should also be considered to maintain the temperature of your water during cold months (Somerville, C. et. al., 2014).

For the layout of the design, you want to make the floating rafts are easily accessible, so a one meter width is preferred. It is also best to design the system so there is room to walk around on all sides, allowing for easy harvesting and maintenance. Finally, you should consider how you will power your system. The pumps require a large amount of electricity, so sustainable methods such as solar panels can be used in areas where electricity is not available or may be too expensive.

Economics

To determine if hydroponic and aquaponic systems are good options for investment, one must consider initial investment costs, market competitiveness, environmental impact, water quality, system complexity and maintenance costs.

The best hydroponic system to invest in commercially would be a Nutrient Film Technique system. Compared to a deep water culture system, it allows for better water conservation, is easier to maintain and has lower maintenance issues (Danner et al., 2019). Hydroponics could be used for producing a personal supply of fodder for livestock because it allows for continual fresh green fodder throughout all four seasons, enabling livestock food security. Market prices of fodder can pose an economic challenge, which a hydroponic system could greatly reduce (Brown, 2019)

Aquaponics is a good investment as it is able to produce 4 kg of leafy greens for every 1 kg of fish farmed (Danner et al., 2019). When this goes to market, it is common to have a net loss in fish production and a net gain in crop production (Engle, 2017). Overall, this does make the average system profitable. As with many economic ventures, it takes an initial investment in a system in order to obtain a profit over time. In a commercial system model in Hawaii, it was found that the return on investment was 7.36% (Tokunaga et al., 2015). Therefore, aquaponics is a viable investment.

Figure 1: Hydroponic and Aquaponic Economics Trends
(Aquaponics market - growth, trends, and forecast, n.d.; Hydroponics market - growth, trends and forecasts, n.d.)

Agriculture Industry

In Namibia, agriculture accounts for 31% of the labor force. Subsistence farming is also commonly practiced, due to the 34% of Namibians' unemployed and the 55% that live in rural areas (Central Intelligence Agency, 2020). Climate change continues to affect this leading industry in employment. The drought has greatly impacted agriculture in Namibia, with food insecurity worsening in early 2020. This was caused by the low 2019 harvest that severely affected subsistence farming (Food and Agriculture Organization of the United Nations, 2020). Drought has long been affecting Namibian agriculture, however. In 2013, drought killed 4,000 animals and affected 300,000 people (UNICEF, 2019). To avoid the continuing effects of climate change on the agriculture industry, new alternative practices are needed.

Yield

Hydroponics and aquaponics both have a higher crop yield than traditional agriculture. In these systems, plants grow much faster and produce more crops in a smaller amount of space. Typically once built, a hydroponics system will only take 6 weeks to be fully functioning and harvest a high yield. In aquaponics, it typically takes up to 6 weeks before you can start growing crops due to the cycling process. It can then take up to a year to reach full capacity as the microbial populations are still adjusting (Storey, 2017). Once your system is at full capacity, crops can be harvested every three to four weeks.

Hydroponics vs. Aquaponics

Nutrient Source:

- **Hydroponics:** Nutrients for plants come from fertilizers put into the water
- **Aquaponics:** Nutrients for plants come from fish waste that is broken down through bacteria

Time to Harvest:

- **Hydroponics:** Plants grown hydroponically can be harvested as soon as 6 weeks after planting (Storey, 2017)
- **Aquaponics:** It may take up to 12 months from initial planting to see a system produce full yield so bacteria colonies can mature

Crops Produced:

- **Hydroponics:** Ideal for growing livestock feed like barley or oats
- **Aquaponics:** Grows herbs sand vegetables well and also produces fish for consumption

System Cycling:

- **Hydroponics:** System requires no cycling prior to planting as the chemical nutrients can be directly absorbed by the plants
- **Aquaponics:** System must be cycled with fish waste water for 6 weeks prior to planting to allow bacteria colonies to grow

Key Guidelines

- Monitor your system's temperature, dissolved nutrient levels, water levels, and pump functionality everyday.
- Provide proper aeration and water circulation with pumps.
- Choose fish and plants based on the climate.
- Avoid overcrowding and overfeeding your fish.
- Keep the tank clean by removing solid waste for aquaponics and periodically renew your water in hydroponics to avoid the buildup of toxins.
- Restock the fish and replant at staggered times to help maintain the balance of plants, fish, and size of biofilter in your system.
- Avoid harmful pathogens or animals in your system.

Future Opportunities

While aquaponics and hydroponic systems can work to address food insecurity and worsening droughts, there are many other steps currently being taken to further address these nationwide challenges. Namibia's Vision 2030 is a long term plan which aims to address education, health care, a clean and productive environment, a profitable economy, rewarding employment, low crime rates, a just society, and meaningful government (Government of the Republic of Namibia, 2004). The Ministry of Forestry, Water, and Agriculture in Namibia also has established a clear mandate to "promote, manage and utilize Agriculture, Water, and Forestry resources" (Government of Namibia, n.d.). Within Namibia's government, hydroponic and aquaponic systems have the opportunity to support these goals. On a global stage, the United Nations has created a set of Sustainable Development Goals such as zero hunger, sustainable communities, good health and several others that can lend support for new practices in Namibia (United Nations, n.d.). These goals validate a sustainable change in industry and daily life to promote food security, economic stability, and well being.

Conclusion

Due to their differences, implementing both an aquaponic and hydroponic system can be beneficial. Although aquaponic systems are more complex, the capability to provide fish as well as vegetables and herbs is beneficial for supplementing the human diet because it produces protein, vegetables, and starches. Hydroponics is a simpler option that requires less maintenance and can operate on a faster harvesting schedule than aquaponics. This type of system is an ideal option for supplementing the diets of livestock. By using both systems, there is great potential to supplement security of food and livestock fodder. It is important to start taking action and using more climate resilient and sustainable methods of agriculture. Using these tips, you can create your own hydroponics or aquaponics systems and improve food security in Namibia.

Glossary

Aquaponics
Aquaponics refers to a system where fish and plants are grown together. Fish waste in the water produces nutrients for the plants and the plants use the nutrients and provide clean, filtered water for the fish (Bernstein, 2011).

Cycling
The process of establishing a biofilter for the nitrogen cycle to take place in the system (Bernstein, 2011).

Food Security
Having reliable access to a sufficient and healthy quantity of food (Government of the Republic of Namibia, 2004).

Hydroponics
Hydroponics is a method of growing plants without any soil. The plants are placed in grow beds and use only water and chemical nutrients (Bernstein, 2011).

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Hanns Seidel Foundation

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Finland-Namibia 150 years of friendship #FinNam150

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Appendix E: Manual Infographic

Appendix F: Links

HSF ThinkNamibia

https://www.thinknamibia.org.na/

Blog

https://aquaponicshsf.wixsite.com/aquaponics

Fact sheet video

https://www.powtoon.com/online-presentation/ek9xfG7zPD4/hsf-aquaponics-project/?mode=movie#/

Manual video

https://www.powtoon.com/c/enhnlqsv3c4/1/m

Aquaponics Prototype Design CAD

https://cad.onshape.com/documents/ccf575d8ab2804673f50ff61/w/286aeb2ca87958cd60d17f1f/e/e644ff03d8878b2bee6d0e0e