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Aquaponics in Saudi Arabia: Initial Steps towards Addressing Food Security in the Arid Region

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Abstract: Due to water scarcity and harsh climate, Saudi Arabia and its neighboring countries rely heavily on fresh food imports from distant lands and have higher per capita expenditures on vegetable imports compared with USA and China. Aquaponics can supply fresh food throughout the year and may complement conventional agriculture in Saudi Arabia to help the objectives and policies defined by the government for food and water security. In this spirit, an Aquaponics farm is being constructed in the desert-coast climate to study the feasibility. A detailed SWOT analysis is performed for a commercial farm which reveals that the advantages of Aquaponics in the Saudi market outweigh the weaknesses. Preliminary experiences show that such ventures require high capital costs and synergistic collaboration of engineering, agriculture, business, and geology.

Keywords: Aquaponics; food security; Saudi Arabia; SWOT; water security

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1. Introduction

In recent years, major factors such as climate change, conflict, and economic fluctuations have caused people to perceive the importance of food security due to frequent disruptions in production and supply chains. These events have also triggered an uncontrolled increase in the global food price index (FPI), which reached a record value in the last decade, with 125.7 points in 2021 [1]. It is anticipated that food prices will continue to increase exponentially due to the recent conflict between Ukraine and Russia which are among the top food commodity producers. Furthermore, the fuel prices following the pandemic have experienced a steeper upward trend because of these events. This has further impacted the cost of food transportation, also called food miles. While an increase in the food price may also reflect the development in a country's economy, a case in point is the developing economies or the countries largely depending on imported agricultural produce, as they will be unable to reach the required goals in terms of food prices and availability soon. This brings up the issue of food security, which is not only limited to the unavailability of food, but also directly related to water security, and encompasses food's quality and nutritional value. Therefore, importing agricultural produce is not a sustainable solution. On the other hand, due to inadequate conditions (or imbalances) resulting from arid climate, water scarcity, population growth and urbanization, energy crisis, soil degradation, and climate change, local food production becomes a significant challenge and impossible in many cases. This is directly related to the nexus of people, planet, and profit, which often leaves the challenge of prioritizing only one of these.

To address these issues, priority should be given to agricultural methods, techniques, and research to ensure sustainable and efficient farming, which optimizes the use of water and energy resources, is close to the market to ensure food security and reduces food miles and produces safe, healthy, and a variety of nutritious products. A possible answer to this is Aquaponics which is an integrated agriculture technology based on a symbiotic relationship between fish, beneficial bacteria, and plants, implying that it is a multi-crop system producing protein and a variety of fruits and vegetables simultaneously by recycling the water and nutrients. The fish (commonly Tilapia, Carp, and African Catfish [2], or others [3]) kept in the water tanks produce waste that contains Ammonia. The naturally occurring aerobic bacteria convert Ammonia to Nitrite and then Nitrates. This Nitrate rich water, which serves as the main plant nutrient, is circulated through the hydroponic section of the system housing the crops. The Ammonia/Nitrate-free water is then sent back to the fish, and the whole cycle is repeated. The members of COST Action FA1205 (the EU's Aquaponics hub) [4,5] proposed the definition of Aquaponics as a "production system of aquatic organisms and plants where the majority (>50%) of nutrients sustaining the optimal plant growth derives from waste originating from feeding the aquatic organisms".

The hydroponic section of these farms may consist of nutrient film technique (NFT) setups, media beds or deep water culture (DWC) channels. NFTs are least favorable for hot weather as there is a significant rise in water temperature from inlet to outlet [6]. Media beds offer multiple advantages such as supporting fruiting plants' root system, media (gravel or river stone) acting as filtration stage for the system and hosting a diverse population of beneficial aerobic bacteria and worm population which ensure nutrient availability for the whole system. However, large-scale commercial systems face the huge challenge of cleaning media beds that, if not cleaned, create anaerobic pockets and turn the system unproductive. DWCs on the other hand, are the most suitable for both leafy greens and fruiting crops. They have a large volume of water compared with the media beds eliminating sharp variations in pH and water temperature which is critical for fish health.

The benefits offered by Aquaponics are significant. For instance, it uses significantly less water than conventional agriculture because water is recirculated [7–9]. This is more pronounced in arid regions, where a water reuse efficiency of at least 95% has been reported [10]. It is a multi-crop system giving pure produce because the use of pesticides or medicines is harmful to fish, bacteria, and plants. It also addresses the issues of food miles, security, and sovereignty because Aquaponics farms are scalable at any level [11], implying that they can be placed in urban settings [12–16], i.e., close to the market, and can be operated in harsh weather conditions [17,18]. In addition, unlike aquaculture or hydroponics, Aquaponics does not require the dumping of wastewater with toxic chemicals into the environment [19]. Being a soil-less agricultural technology, it is possible to build Aquaponics farms on non-fertile land, as it is being done in South Africa on degraded coal mining sites [20]. It was reported that the net profit from an Aquaponics system is 30-fold higher than conventional agriculture due to efficient use of the growing space and additional income from the fish in Egypt [6].

The word Aquaponics was first coined in the 1970s; it has roots in New Alchemy Institute in Cape Cod USA. From the late 1970s to 2000, mainly two groups were doing significant research work on the subject, namely Dr. Mark McMurtry from North Carolina, and Dr. James Rakocy from the University of Virgin Islands (UVI). Later used a series of DWC beds to grow vegetables in water, and Tilapia was raised in the tanks; the research was carried out for a period of 25 years. The main limitation of this system was an extremely high fish density (fish mass per unit volume of water) which required extensive filtration [21]. Nevertheless, this system provided design basics and theoretical background for state-of-the-art Aquaponics systems. Throughout the first decade of 2000, several research projects were initiated that built upon the early works of Dr. Mark McMurtry and Dr. James Rakocy. The research outcomes from these projects were studied by [22,23], which emphasized the need for pursuing Aquaponics farming on a commercial scale.

An extensive research database is available on the subject and continues to grow, and numerous researchers from around the globe have been contributing to various related topics, as seen in Figure 1.

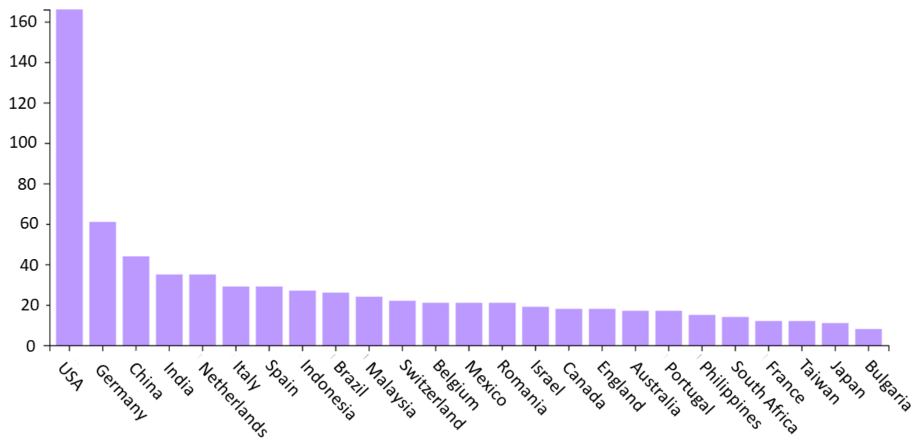

Figure 1. Number of publications on Aquaponics vs. geographical location.

In addition, online courses and certifications are available which give a basic knowledge of setting up a small-scale Aquaponics farm. These farms are operational in almost every continent, and range from small-scale backyard farms (majority) supporting a family or community, such as in Africa [6], to large-scale commercial farms (very few). Two of those farms that must be mentioned here are in Oman and Bahrain, where the weather conditions are similar to the region under study, i.e., the Eastern Province of Saudi Arabia—a desert-coastal region. However, there are differences in the market dynamics of these countries when compared with Saudi Arabia. Aquaponics was established in Saudi Arabia for the first time at King Abdulaziz City for Science and Technology (KACST) in Riyadh [9]. There are a few commercial aquaponics projects running in Riyadh and Jeddah (personal communication); due to their commercial nature, most of the knowledge is confidential.

Despite significant research contributions and the coverage given to Aquaponics by news and media, this field is still in its infancy, and there are no mature methodologies to meet commercial objectives. They have not been able to address the issues required by the policymakers and governments to support this type of farming on an industrial scale. The studies and systems that do exist, are suitable for a particular climate and region, necessitating the study and experiments conducted for every prospective geographical area. These challenges are a direct result of the fact that Aquaponics is an engineered natural system where one has to adapt to the system requirements, as opposed to the common industry practice of forcing the system to adapt to one's necessities. In addition, as reported for Egypt [6], Aquaponics is profitable only in the long term because the capital and operational costs are higher than conventional agriculture, often discouraging farmers and entrepreneurs to start a new venture [17].

Following this line, two recent reviews [24,25], surveyed the existing research database on the subject and have analyzed it from various perspectives ranging from technical to commercial, concluding that many variables come into play which makes Aquaponics interdisciplinary, unique, challenging, and highly dependant on the geographical location. Specifically,

- extreme weather conditions demanding costly water temperature and climate control technology,
- choice of suitable fish species and crops depending on their profitability, weather conditions, farmer and consumer preference, system capacity, and type and quality of water [17],
- materials available locally, which directly influences the investment and running costs,
- suitability of local market dynamics and lifestyle because the product can be certified as organic, and
- limited capability and experience of technical people [6].

Only a few Aquaponics farms have shown commercial feasibility, and one can only find a handful of courses that offer parameter values and methodologies, however, they are based on trial and error, and long-term empirical studies in various locations around the world. Most of the existing literature is based on short trials [26], small-scale systems, and varying experimental conditions and designs [22,27,28]. The review presented in [28] dealt with this problem by targeting the standardization process for Aquaponics research with the definition of critical parameters, and aspects and performance indicators for these systems. The main motivation was to help commercial aspirants to have a systematic basis for developing and maintaining these systems.

From an economic standpoint, the planning of an Aquaponics business venture becomes challenging because there are only a few studies on the annual running costs of the involved systems, and the majority of them are based on hypothetical situations that are very optimistic and do not take into account unforeseen costs [29]. Furthermore, these studies are valid for regions where the climate and market conditions are completely different from Saudi Arabia, where only a few small-scale studies have been reported based on a limited number of variables. For instance, an indoor Aquaponic system with Tilapia and Lettuce was reported by [9]. Being an indoor system with only a DWC component, the system's dynamics, waste management, and water loss to evaporation and evapotranspiration differ considerably from an outdoor system. Moreover, commercial aspects of the system were not considered and only the fish feed-to-plant ratios were studied. Another study [30] discussed Aquaponics from a fish farming perspective in Saudi Arabia and emphasized introducing training programs at the governmental level to encourage people to start home-based systems, thus improving dietary diversity and value, and adding to the income source.

Therefore, providing a framework for such farming in the weather conditions of Saudi Arabia, would not only positively contribute to the region's social, environmental, and economic ecosystem, but also provide guidelines for similar climatic conditions in other arid countries, which is missing in the literature. To the best of the authors' knowledge, SWOT analysis of an Aquaponics farm in Saudi Arabia, or any other arid country has not been reported. Following this line, a detailed SWOT analysis is presented concluding that these types of farms offer significant advantages and commercial edge compared with other farming techniques, despite the presence of vulnerabilities and threats. Initial construction and development experiences are also reported with the motivation that the commercial aspects will be analyzed to study the possibility of introducing Aquaponics at a large scale in the arid region.

2. Background

This section gives a background about Saudi Arabia's climate, water threat scenario, and food imports which presents the motivation to introduce efficient agricultural techniques, such as Aquaponics.

2.1. Climate

According to Köppen-Geiger [31], the climate classification of Saudi Arabia is arid, desert, and hot arid. Generally, the summers are extremely hot with the temperatures reaching 50 °C and getting very humid in the coastal regions. In addition, significant variations can be observed in temperatures between a typical day and night. The country gets long-term annual rainfall of approximately 70 mm [32]. Climate change has triggered extreme weather events, such as droughts and increased temperature, flooding, and fire events in arid and semi-arid regions. Especially in the MENA region, extreme heat is projected, and the temperature is expected to reach up to 56 °C [33]. This type of climate shows that a protected cropping strategy with effective climate control might be the only solution to growing food locally in the future [34].

2.2. Water Scarcity

The MENA region has around 6% of the world's population [35], and only 1.4% of the world's freshwater is available, classifying it as the world's most water-stressed area [36,37]

The water demands in agricultural and other sectors of Saudi Arabia are satisfied with renewable and non-renewable groundwater, surface water, desalinated water, and treated wastewater, where the non-renewable groundwater was used the most according to the country's Ministry of Environment, Water and Agriculture (MEWA) [38]. In 2009 and 2014, the total water demand for agriculture was 84% and 78% of the total water consumption, respectively [39]. In 1984, the Ministry of Agriculture and Water (MAW) reported that the proven, probable, and possible reserves of non-renewable groundwater were 253, 405, and 705 billion m^3, respectively. However, according to Food and Agriculture Organization (FAO), approximately 42% of the proven reserves might have been consumed by 1996. To give a perspective, total renewable water sources per capita for Saudi Arabia have decreased by roughly 35% from the year 2000 till date [40]. These consumption rates are alarming given that Saudi Arabia is at high water risk. Moreover, the available water resources may not be enough to support all the sectors in the long-term [41], posing a serious threat to water security in the region.

2.3. Food Imports

It is anticipated that by 2050, Saudi Arabia may import all of its food items [42]. In the year 2019, fish imports exceeded US$ 19 million, where the majority was imported from UAE and Asia Pacific [43]. For the same year, vegetable imports mounted to over US$ 8 billion, implying roughly US$ 240 per capita annual expenditure. This is higher than USA, and at least four times that of China for the same year [44], as shown in Figure 2.

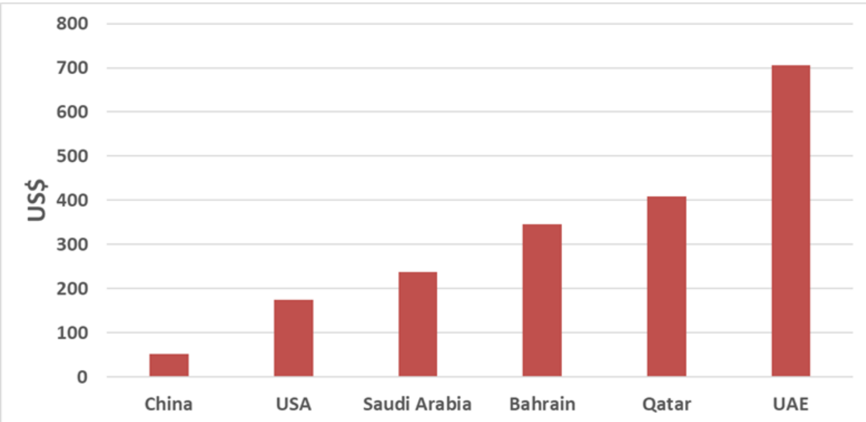

Figure 2. Vegetable imports per capita in US$ for 2019. Data from [44].

The major import countries were India, USA, Argentina, Indonesia, and Egypt, as shown in Table 1, which compiles per capita vegetable imports for China, USA, UAE, Bahrain, and Qatar. This shows the heavy reliance of Saudi Arabia on fresh food imports from distant countries, making the issue of food security and sovereignty more pronounced. The same is true for the neighboring countries, which have even higher per capita expenditures on imports. In contrast, USA imports most of the vegetables from northern and southern neighboring countries, all of which are connected by land.

Table 1. Vegetable imports per capita and major import countries for 2019. Data from [44].

Country	Annual Imports per Capita [US$]	Major Import Countries
Saudi Arabia	237	India, USA, Argentina, Indonesia, Egypt
UAE	705	India, USA, Canada, Iraq, Spain
Bahrain	346	India, Australia, Saudi Arabia, UAE, USA
Qatar	406	India, Iran, Russia, Pakistan, USA
China	52	Brazil, USA, Thailand, Indonesia, Canada
USA	175	Mexico, Canada, Colombia, Chile, Peru

2.4. Initiatives and Actions by Saudi Arabia

To deal with water scarcity, several initiatives have come to action to optimize water usage and reduce its extraction from groundwater sources. These include automation of irrigation systems in main agricultural areas, studying the possibility of artificial aquifer storage, limiting the usage of groundwater, and introducing mandatory water systems optimization for all major construction projects, to name a few. One of the recent actions was to suspend the production of water-intensive crops, such as wheat and fodder [45]. Although these actions are effective in reducing groundwater extraction, they may not be enough to obtain sustainable management of water resources.

The country has set Vision 2030, which specifically states to build safe and sufficient strategic food reserves for emergencies such as aquaculture farms and prioritize agricultural water use for the areas with natural and renewable sources. Most importantly, it promotes the optimal use of water resources by reducing consumption and utilizing treated and renewable water. To achieve the strategic objectives, the country has developed realization and transformation programs to improve joint work and planning.

3. Aquaponics in Saudi Arabia

Given the above-stated facts, one can appreciate the need for introducing Aquaponics on a significantly larger scale in Saudi Arabia. Moreover, the fast-changing mentality and lifestyle of people in the country to shift toward a health-conscious diet, the impact Aquaponics can have on multiple socio-economic aspects, and that it addresses the food security and water scarcity issues, it is clear that Aquaponics in a controlled environment may complement conventional agriculture to support the objectives and policies defined by the government for sustainability [42]. An example of this was reported for Kenya [6], where an exploratory survey for the market revealed that the people were willing to pay a higher price for fresh and healthier produce from Aquaponics farms.

In this spirit, an Aquaponics farm is being constructed in Saudi Arabia near the East coast which has a peculiar desert-coast climate, to initiate a first-ever commercial study for the country. As the first step of any commercial venture, a detailed SWOT analysis is conducted to gauge the feasibility and marketability of the Aquaponics product. This analysis can be used as a framework and guideline for such projects, particularly targeted for arid weather conditions. Next, critical aspects of the construction and sourcing phases of the development are reported, which emphasize the challenges one can expect in building such farms.

3.1. SWOT Analysis

The analysis is performed to capitalize on the strengths and opportunities and identify the weaknesses and threats to find suitable solutions, which can make the Aquaponics farm a feasible venture given the local factors such as the environment, market dynamics, and the available expertise.

3.1.1. Strengths

1. **Produce:** Superior quality, fresh, consistent yield, uniform growth, high nutritional value, longer shelf-life.
2. **Revenue sources:** Retail, food & beverage (restaurants) and B2C sector, training and workshops, agri-tourism, supplies, and services.
3. **Competencies:** Low water usage, the possibility of decentralized and urban agriculture (can be done at roof-tops and backyard) [14], protected cropping, 100% organic and chemical-free, very low probability of disease compared with hydroponics and aquaculture, proximity to market implying lesser food miles and packaging costs, soil-less.
4. **Overall advantages:** Compliant with environmental safety standards and regulations, lack of market competition, resource-efficient, solar power, and geothermal integration is possible.

3.1.2. Weaknesses

1. **Environment:** Dealing with high temperature and humidity cost-effectively, availability of acceptable water quality.
2. **Sources of revenue loss:** Extreme temperatures, sand storms, higher energy costs due to climate control, pests.
3. High capital costs for farm construction.
4. Needs specialized knowledge, which is still lacking in terms of expertise and skill set.

3.1.3. Opportunities

1. **Availability of technology:** Superior transport infrastructure, well-connected road network throughout Saudi Arabia and the Middle East, greenhouse climate control technologies are available, possible to procure state-of-the-art technology due to the existing mature oil and gas sector.
2. **Government policies:** Vision 2030 and MEWA water strategy envision water and food-secure country.
3. **Customer:** Shift towards an organic and healthy diet, awareness about health-conscious lifestyle, environmentally responsible farming.
4. **Market voids:** Absence of economical organic options for the consumer, fresh local produce is highly seasonal and mostly inorganic, poor shelf life of imports.
5. **Favorable trends:** Preference for local produce with environmental benefits and superior freshness.

3.1.4. Threats

1. **Obstacles:** Volatile markets, cheaper alternatives become favorable as FPI rises, imported alternatives constantly penetrating the marketplace, getting organic and chemical-free certification from Saudi food and drug authority (FDA) for Aquaponics, spreading awareness among the locals.
2. **Economic factors:** Trade and purchasing patterns are highly dependent on econo-political conditions, and high labor and import costs in the country.
3. **Vulnerabilities:** Balancing between customer demands and weather conditions, weather-suitable crops limit the crop variety, and penetration in the market might require low initial prices.

3.2. Building a New System

In this section, a walk-through of the process of planning and building the Aquaponics facility is presented. Those aspects which are particular and critical to the development in such region are highlighted, giving a glimpse into cost-intensive areas that may require trade-offs. The farm is located on the King Fahd University of Petroleum and Minerals (KFUPM) campus in the city of Dhahran, which is less than 10 *km* away from the Arabian Gulf coast.

3.2.1. Site Survey and Preparation

The process starts with surveying the available land for inspecting its slope, sun angles, wind direction, local climate, nearby facilities, the possibility of excavation and any related challenges, availability of water and its quality, and electric utility availability, quality, and rating.

One of the challenges for Aquaponics is the maintenance of acceptable water temperature, i.e., in the range of 23 to 28 °C. An economical way is to utilize the geothermal effect, which requires excavation of several meters below the ground level to bury the sump, thus having a direct impact on the construction cost. The required depth was studied using the well-known fact that underground temperature is a function of time of year, depth, ambient temperature, and thermal properties of the soil [46]. Specifically, it is defined as,

$$T = T_{mean} - T_{var}\ e^{-z\sqrt{\pi/365\alpha}}\ cos\left[\frac{2\pi}{365}\left(t_{year} - t_{shift} - \frac{z}{2}\sqrt{\frac{365}{\pi\alpha}}\right)\right], \quad (1)$$

where, T is the temperature of soil, T_{mean} is the mean surface temperature, T_{var} is the total variation from T_{mean}, z is the depth in m, α is thermal diffusivity measured in m^2/s, t_{year} is the current day of the year, and t_{shift} denotes the day at which surface temperature is minimum, i.e., $T_{mean} - T_{var}$. Using the parameter values given in Table 2, T values at various depths ranging from 1 to 50 m were calculated and they are shown graphically in Figure 3.

Table 2. Parameter values used for geothermal calculations.

Parameter	Value
T_{mean}	26 °C
T_{amp}	24.5 °C
α	0.566 m^2/day [47]
t_{shift}	12 days

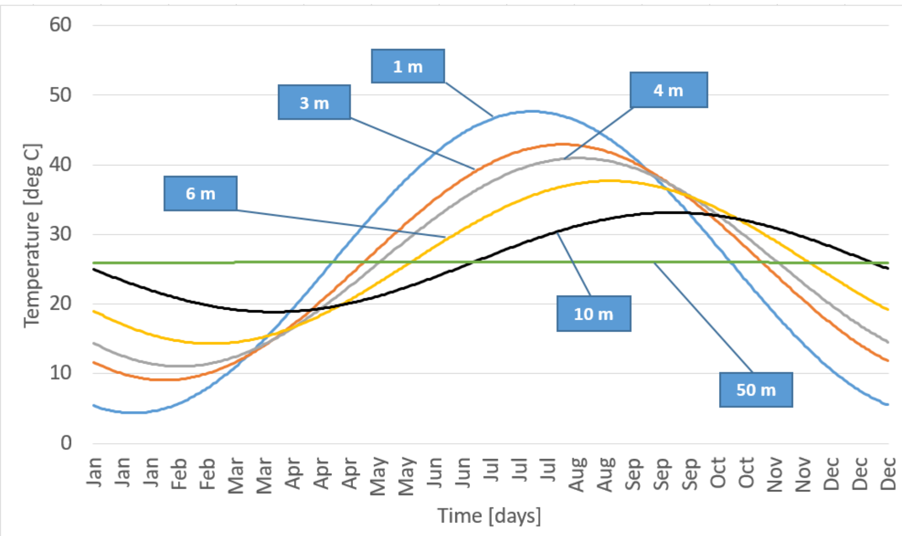

Figure 3. Annual ground temperature variation in Dhahran, Saudi Arabia at various depths.

It can be seen that an ideal depth would be more than 10 m to have acceptable water temperature regulation. However, it was found that the area consisted of a sewage line and electric utility installation of roughly 3 m underneath a hard rock (Figure 4) and limestone, increasing the excavation cost and limiting the depth to less than 3 m. Therefore, it is expected that the water temperature may rise above 30 °C. To counter this situation, the sump capacity is doubled the required volume by increasing the diameter of the tank, and aquarium chillers are installed to be operated only if necessary.

The weather data of King Abdulaziz Airbase was chosen, which is within a 4 km radius of the selected location. The monthly temperature and humidity variation for this area for 2018 is given in Table 3, which shows that the winters are cool and range from November to February. The summers are extremely hot with the temperature reaching 50 °C. This city being less than 10 km away from the Arabian Gulf coast observes a high amount of relative humidity. In addition, extreme sandstorms occur at least once a year where the temperature drops by a few degrees because of sunlight blockage by suspended sand particles. Only a few months get moderate rainfalls, i.e., February-March and November-December. Most of the wind blows from North-West and Northern directions all year round.

Figure 4. Excavation for installing sump.

Lastly, before starting the actual construction detailed designs were prepared including the plumbing specifications, as shown in Figure 5. This helped the construction contractor to understand the scope of work.

Table 3. Weather data for Dhahran, Saudi Arabia for the year 2018.

Month	Max/Min Temperature [°C]	Max/Min Relative Humidity [%]
January	27/6	94/6
February	36/6	94/8
March	41/12	100/6
April	40/18	88/6
May	45/22	69/6
June	49/27	70/6
July	48/28	89/6
August	47/26	79/6
September	47/23	89/5
October	43/16	83/8
November	33/14	88/24
December	29/11	94/26

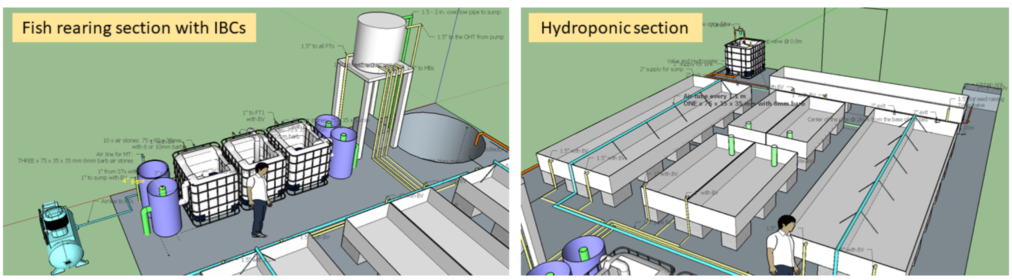

Figure 5. A screenshot of the farm plan and plumbing details prepared before starting the construction.

3.2.2. Sourcing

Aquaponics is an interdisciplinary field that requires expertise in civil engineering, plumbing, aeration systems, aquaculture, hydroponics, and agriculture, to name a few. An inherent challenge in this kind of project is the availability of components and their integration. This requires the project manager to have significant knowledge of all these aspects, and a well-connected team to accomplish the task of bringing all these systems together. In addition, the availability of all the components might not be possible, and importing them may be the only option, where the custom and import regulations might affect the timeline of project completion. Therefore, this aspect must be taken into account at the startup stage to avoid contingencies. Higher costs may jeopardize the viability of the project, therefore importing should be avoided as much as possible.

The sourcing of metallic parts also requires special attention as they can corrode from the acidic water in the system, thus hindering food safety certifications. Following this line, stainless steel (SS) should be used; for instance, water pump impellers manufactured from SS304.

3.2.3. Grow Beds

Following the advantages mentioned above for each type of grow bed in the hydroponic section, DWC has a 22 m^2 grow area and media beds have 10 m^2 to maintain the balance between nutrient availability and water parameters regulation. The availability of media is a challenge in Saudi Arabia because the commonly used river stone can only be imported. In addition, it may need to be changed every few years to avoid sludge buildup, thus significantly raising the capital and operational costs. An alternative to this is expanded clay pebbles which are at least four times less in cost and extremely lightweight compared with the stones.

Another aspect of grow beds is their ergonomic design and installation to ensure a smooth working environment during planting and harvest cycles. For this reason, the land was leveled and the grow beds were raised to waist height as shown in Figure 6, which also avoids pests. Although it slightly raises the cost and the required labor in the development phase, it is important for operations.

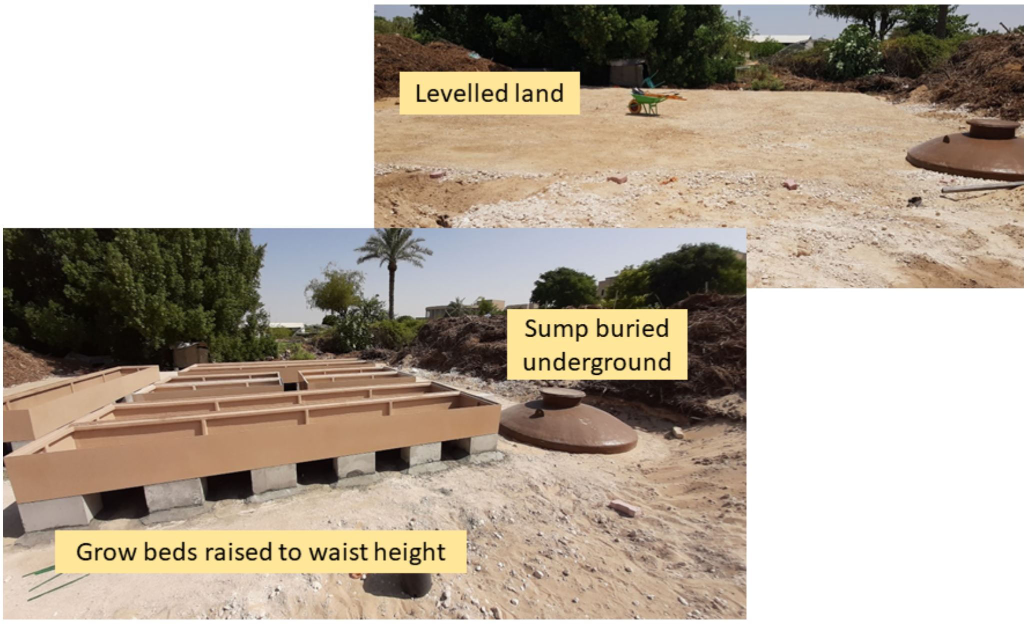

Figure 6. Land leveling and grow beds raised to waist height using concrete blocks.

3.2.4. Greenhouse

The Aquaponics farm in Oman used an open-type, naturally ventilated greenhouse design as shown in Figure 7. However, being custom-made, the manufacturing cost was roughly five times that of a readily available greenhouse for the case under study. Moreover, the risk of attracting pests is higher, therefore a ready-made fiberglass greenhouse with 70% blocking shade cloth was used, as shown in Figure 8.

To keep the temperature cool inside the greenhouse, fan and pad systems are generally used, however, they are water-intensive and do not guarantee uniform temperature across the greenhouse. Therefore, suitably sized exhaust fans were installed for ventilation and movable desert coolers were placed close to the grow beds to cool the air volume right above the grow beds, i.e., where it is required the most.

Figure 7. Open type naturally ventilated greenhouse used in Oman Aquaponics farm.

Figure 8. Fiberglass greenhouse with 70% blocking shade cloth installed.

3.2.5. Fish Rearing Section

Similar to the case of the hydroponic section, the fish tanks should be ergonomically designed and installed for ease of harvest. In a commercial case, round tanks manufactured from fiberglass are used, however, they are expensive. A cheaper alternative to these is the Intermediate Bulk Container (IBC), which is used to transport food products and is readily available in most parts of the world. Although it is not the perfect replacement for a round tank, they serve the purpose of small-scale systems.

3.2.6. Air Supply

Both DWC and fish-rearing sections need aeration supplied by an air pump. In aquaculture farms, usually regenerative air blowers are used, however, they require a cool environment to operate which is typically at 30 °C. This implies installing energy and cost-intensive air conditioning units. An alternative to these for a hot climate may be a piston air compressor accompanied by an air tank that operates on a duty cycle. They require regular maintenance and suitable filters at their output to filter out sand or other unwanted particles, oil, and water. These are chosen for the system, and their effectiveness will be observed during the operation phase.

3.2.7. Instrumentation

To conduct a detailed study of the parameters and their yearly trends, the water temperature at three points in the system, i.e., the sump, DWC bed, and the fish tank will be monitored. Daily monitoring of Dissolved Oxygen (DO), pH, Ammonia, Phosphates, Nitrite, and Nitrates will be scheduled for the fish tanks and horticulture beds (DWC and media beds). Weekly sampling will also be attempted for Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). In a commercial system, water temperature, pH, DO, TDS, Ammonia, Nitrite, Nitrate, and Phosphate in the fish tanks and in the horticulture beds at any two points may be adequate.

3.2.8. Supplementation and pH Management

In these systems, pH tends to go down because biofiltration is an acid-generating process, therefore, buffering with carbonates or hydroxides of Calcium and Potassium is the most practical method of managing the pH and supplementing the Calcium and Potassium in the system. Iron chelate is also added regularly in the sump to balance the nutrients for growing plants [48].

3.2.9. Backup System

The most delicate component in the system is the fish, which require a continuous exchange of water and aeration to avoid stress conditions that can lead to disease or even fish death. Avoiding such situations is critical for a commercial operation requiring the implementation of a comprehensive backup strategy. This may include, backup water and air pumps installed in the fish tanks, which are powered by a backup power source in case of a power failure. This is adopted in the system being developed.

A backup power source may also be necessary for locations where the utility power is not reliable, such as developing countries. Such power sources include diesel generators or solar PV systems with a battery bank, raising the real-estate requirements and costs.

4. Results and Discussion

A commercial-level study for Aquaponics farms has not been reported in the literature, specifically for arid regions. In this spirit, a farm is being built and is in its final stages of completion. A detailed SWOT analysis was performed for a prospective commercial farm viewed from various aspects in detail to analyze its strengths, highlight its weaknesses, identify the opportunities and report possible threats to such projects. These include the products, external factors, and technical, social, and market-related aspects. The advantages that Aquaponics offers are evident for the local market and encourage initiating these ventures mainly because such farms can fill the market void by supplying fresh organic products. Moreover, it is possible to overcome the shortcomings as follows:

- The availability of state-of-the-art climate control technology can solve the problem of protected cropping.
- Increasing awareness among the masses about Aquaponics with a well-designed marketing strategy, which will assist in getting the necessary certifications and clarify any doubts regarding food safety.
- Higher startup costs can be reduced with the introduction of cheaper alternatives, such as recyclable items, and also by introducing small-scale farming instead of large-scale commercial setups, which will support the concept of decentralized agriculture to reduce food miles,
- Avoiding the use of imported components and material as much as possible,
- Training programs at a national level can cover the lack of experienced manpower [30], and universities can play an important role in this area,
- Target staple products (such as tomatoes) besides the exotic varieties, which are usually required by high-end customers, and
- To have additional revenue streams by offering Aquaponics courses, workshops, agri-tourism, and supplies and services.

The preliminary experiences gained in building a commercial farm suggest that Aquaponics demands skills in a spectrum of fields, such as engineering, biology, agriculture, business, management, and in some cases geology, and for them to work synergistically. This is deemed necessary to make such ventures successful on larger scales. There is also a need for local universities to run collaborative research programs to develop mature technologies and methodologies tailored to the needs of the peculiar weather and market dynamics. Once matured, these programs can train people and potentially attract them towards startup ventures. While constructing the farm, capital costs data is being collected, and it is anticipated that the harvested produce will be available in a commercial outlet. This will give real insights into the operations and profitability of such systems in harsh weather and arid climate.

5. Conclusions

This paper discussed the problems which Aquaponics may be able to solve in the context of food security in Saudi Arabia and complement the agricultural ecosystem given the advantages discussed above. A detailed SWOT analysis was performed for a prospective commercial farm and it was concluded that the advantages in the Saudi market outweigh the weaknesses and threats due to the market void, whereby organic products are mostly imported. Moreover, it is possible to overcome the shortcomings given the availability of state-of-the-art technologies and resources. The preliminary experiences of sourcing and construction were also reported which revealed the requirement of high capital costs and the demand for skilled labor, interdisciplinary technical expertise, and most importantly synergistic efforts from the entire team.

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Abbreviations

The following abbreviations are used in this manuscript:

SWOT	Strength, Weaknesses, Opportunities, Threats
FPI	Food Price Index
MENA	Middle East and North Africa
NFT	Nutrient Film Technique
DWC	Deep Water Culture
UVI	University of Virgin Islands
MEWA	Ministry of Environment, Water and Agriculture, Saudi Arabia
FAO	Food and Agriculture Organization
B2C	Business-to-Consumer
FDA	Food and Drug Authority
SS	Stainless Steel
IBC	Intermediate Bulk Container
DO	Dissolved Oxygen
TSS	Total Suspended Solids
TDS	Total Dissolved Solids

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