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Group 10229

- Abdelhamid Ahmed
- Abdelrahman Ayman
- Mohamed Ihab
- Youssef Mostafa

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Introduction

Egypt is currently regarded as a developing country on the verge of industrialization. Egypt's prosperity has not been new throughout the ages, with a civilization that is over thousands of years old and has never died, proving its existence.

Egypt is a prime example of how wise policies can lead to the establishment of great civilizations. Furthermore, Egypt's government has made significant efforts in recent years to achieve long-term development and political and economic stability. However, there have been significant problems that have made Egypt's development goals challenging. These issues are classified into several categories based on their economic, social, and environmental aspects. Nonetheless, almost all of them can be attributed to 11 main challenges known as "Egypt Grand Challenges," which are known to be the major causes of hindering Egypt's development and sustainability. These challenges are shown in Figure (1) and include:

- ❖ Improving the scientific and technological environment for all.
- ❖ Adapting and mitigating climate change.
- ❖ Retaining and recycling wastes.
- ❖ Increasing the industrial and agricultural base.

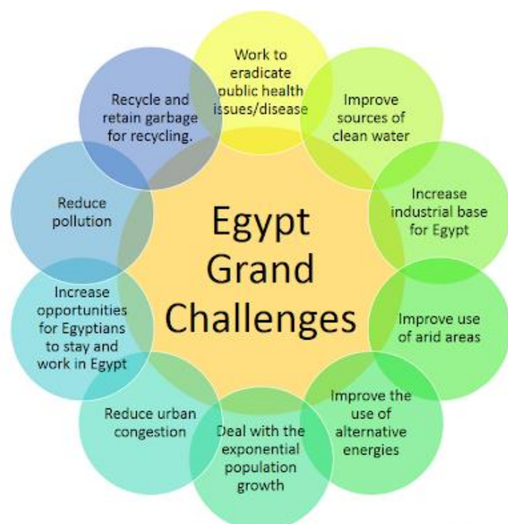


Figure 1: Egypt Grand Challenges that are concerned with its economic, social, and environmental development.

Many studies have been conducted to help describe these issues and investigate their origins and effects. Scientists and experts from various fields have been working to develop approaches for potential solutions to these challenges. With recent discoveries and inventions, the picture created for these challenges has changed dramatically over the years. Nonetheless, concentrated efforts are made because a correct understanding of these problems is critical in order to generate promising solutions.

Chapter I: Present and Justify a Problem

1.1: Egypt Grand Challenges

Reduce and Adapt to the Effect of Climate Change

Overview:

Climate change refers to the long-term shifts in the average weather conditions over a region, which can be as large as the whole world. Scientists currently believe that climate change started in the late 1800s, which coincided with the eminence of the industrial revolution. Climate change is usually associated with other phenomena, including the increased release of greenhouse gases and deforestation (*Causes and effects of climate change* 2022). Climate change is mainly caused by the greenhouse effect and ozone depletion, which are linked to an increase in greenhouse gases and chlorofluorocarbon emissions.

With its large population and projected increase in heat waves, Egypt is a country that is highly vulnerable to climate change. Figure (2) shows the emissions of some sectors in Egypt. Even though Egypt's carbon emissions are limited compared with countries such as India and the United States, the wind currents which are prevalent in Egypt's surrounding regions make it highly impacted by global emissions.

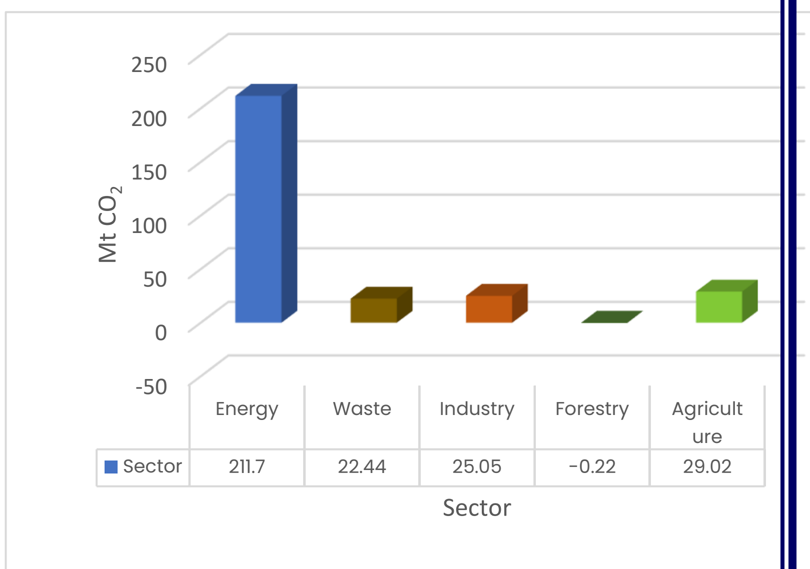


Figure 2: Emission by sector in Egypt (Global climate change *2020).*

For instance, the severity of droughts will increase, especially since 86% of Egypt's land is considered among the driest lands in the world. Subsequently, agricultural land fertility will be affected; a global temperature rise of 1.5 C° can prevent the germination of most basic crops, including wheat. Furthermore, the rise of seawater levels threatens inhabited areas on the northern coast. In fact, over 5 governorates, including Dakahlia and Alexandria might be impacted severely if a water level rise of 100cm took place.

Figure (3) shows major statistics related to Cairo's climate over the year. The data show that Cairo, as well as other major cities in Egypt, are more impacted than before by climate change.

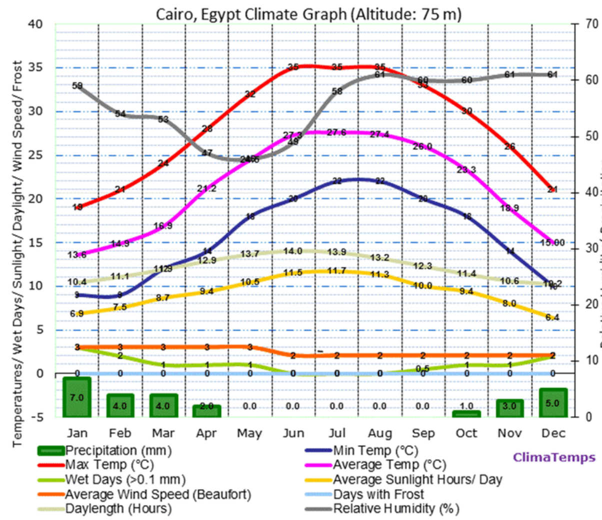


Figure 3: Cairo Climate Graph shows that the climate of such city has been greatly affected by climate change and global warming (Al-Zu bi & Mansour, 2017).

Nevertheless, significant initiatives have been taken to face climate change, including signing the Kyoto Protocol and the Paris Agreement and hosting the Climate Summit. In fact, Egypt has taken different procedures to combat climate change, including establishing green bonds in the MENA region, and updating its targets for the 2030 vision to include reduced emissions and establishment of various sustainability projects. However, the efforts made are not considered satisfactory, and the problem persists. Subsequently, the next section will proceed to analyze the effects and impacts of this serious challenge.

Causes:

Burning Fossil Fuels:

Fossil fuels are the main drivers of climate change, contributing to nearly 90% of total carbon dioxide emissions. The emissions produced whether from the direct burning of fuel in transportation means or from thermoelectric generation lead to the formation of acid rains, which subsequently affect soil pH, essential microbial communities, and water composition. Moreover, the water that is used for cooling in thermoelectricity and thrown afterward in oceans and lakes contributes to raising the temperature of the water, which leads to a decrease in dissolved oxygen and the death of heat-sensitive creatures.

Deforestation and Arid Areas:

According to GlobalForestWatch, Egypt has about only 18.4k hectares of forestry as of 2020, covering about 0.045% of Egypt's land area. The prevalence of arid areas and the removal of green areas in various urban regions contribute to the issue by decreasing rates of carbon dioxide absorption. Moreover, as 95% of Egypt's land area is considered arid and semi-arid, the fertility of soil and water evaporation rains are affected, which leads to more severe climate change impacts.

Increasing Livestock Emissions:

Livestock is considered the main contributor to greenhouse emissions in the agricultural sector. In fact, a single cow releases about 100 kg of methane each year. Methane is emitted primarily due to anaerobic digestion taking place by methanogenic archaea in livestock guts as well as content in animal manure. Although methane is more short-lived than CO_2. Its potential as a greenhouse gas is higher 28 times than carbon dioxide. (Quinton, 2022). Subsequently, Egypt maintains a herd size of about 10 million heads, which is increasing yearly due to overpopulation as shown in Figure (4), livestock emissions represent a cause of climate change which can be more significant than burning fossil fuels.

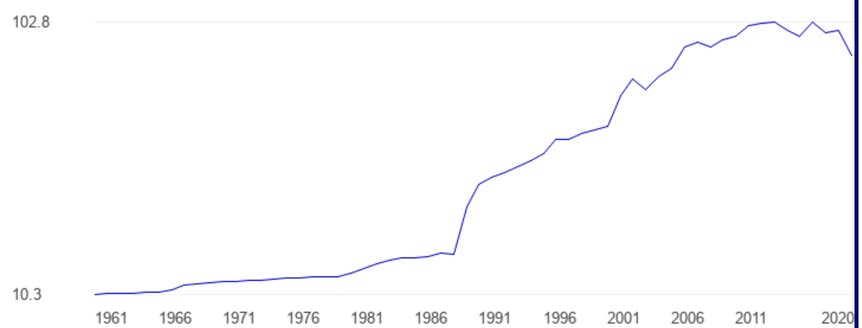


Figure 4: Global Livestock Production Value Index for Egypt over years.

Impacts:

Sea level Rise (SLR):

Due to the melting of land ice and glaciers, climate change is expected to significantly contribute to rising sea levels worldwide. Moreover, SLR is predicted to affect significantly low-level deltas over the world, including the Nile Delta coast. The fertility of soil can be remarkably worsened due to the intrusion of saltwater in Nile water, and soil can be partially or completely eroded by sea waves coming from the Mediterranean sea. Further, saltwater intrusion can contaminate freshwater aquifers, which provide agricultural water supplies and natural ecosystems.

It is expected that about 7 governorates would be directly impacted, including Alexandria; Alexandria's governorate is economically, socially, and physically vulnerable to accelerating SLR rates. In fact, according to the geography of Alexandria, about 35% of the land is below the mean sea level, excluding Lake Mariout (El-Raey, 1995). A rise of 0.5 meters can remove almost all beaches in the governorate, which also would affect tourism negatively.

Public Health Issues and Diseases Spread:

Each year since about 2008, more than 20 million people worldwide have to immigrate because of events related to catastrophic weather. Nonetheless, climate change is already having an impact on public health. Weather and climate changes can endanger people's lives. Heat is one of the most dangerous weather conditions. More than 5 million deaths yearly have been attributed to extreme temperatures in tens of countries (Gustafsson, 2022). Hurricanes become stronger and wetter as ocean temperatures rise, causing both direct and indirect deaths. Dry conditions fuel more wildfires, which pose numerous health risks. Increased flooding can result in the spread of waterborne diseases, injuries, and chemical hazards. The unfortunate fact is that although developed countries are the main contributors to climate change, developing and poor countries are affected the most as shown by statistical evidence. Figure (5) shows the estimated number of Disability-Adjusted Life Years (DALYs) for different regions. DALYs represent the loss of healthy or productive life years (Abdul Rahman, 2012).

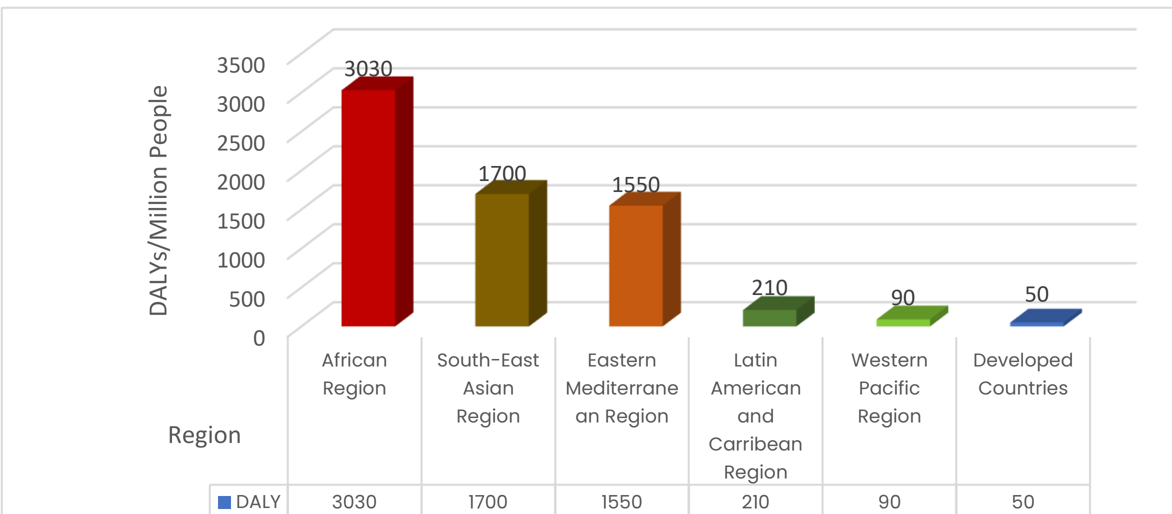


Figure 5: Expected DALYs differ in many regions.

In fact, according to the World Health Organization (WHO), climate change is predicted to be the cause of nearly 250,000 deaths yearly from 2030 to 2050 due to malnutrition, turbulent weather, and the spread of diseases. (*Climate change and health* 2021). Moreover, many contagious diseases, including malaria, are expected to have a wider geographical range due to global warming which makes previously colder areas warm enough for pathogens to thrive.

Improve the scientific and technological environment for all

Overview:

By the beginning of the 21st century, science, technology, and innovation (STI) had been a key driver in the economic growth of many developed countries. South Korea has been transformed from one of the poorest countries in the world to a high-income country in just over half a century, largely due to its investments in these sectors. However, in recent years, the country has been suffering from complicated challenges in revising its scientific and technological environment. According to the Global Innovation Index Report 2022, Egypt ranks 89 out of 132 countries in terms of technological readiness, which indicates the need for a major upgrade in those fields (Soumitra et al., 2022).

In fact, the scientific and technical journal articles count about 13 thousand compared to developed countries like the United States, 420 thousand papers, and China which exceeds 500 papers (*Scientific and Technical Journal Articles - Egypt, Arab Rep. | Data*, n.d.). In addition to that, Although Egypt's patent application has been increasing as shown in Figure (6), it still so far compared to other countries. For comparison, the world average in 2020, based on 117 countries, is 19040 patent applications, while Egypt's patent applications don't exceed one thousand. This suggests that there is a lack of innovation and creativity in Egypt's STI sector (*Egypt Patent Applications by Residents - Data, Chart*, n.d.).

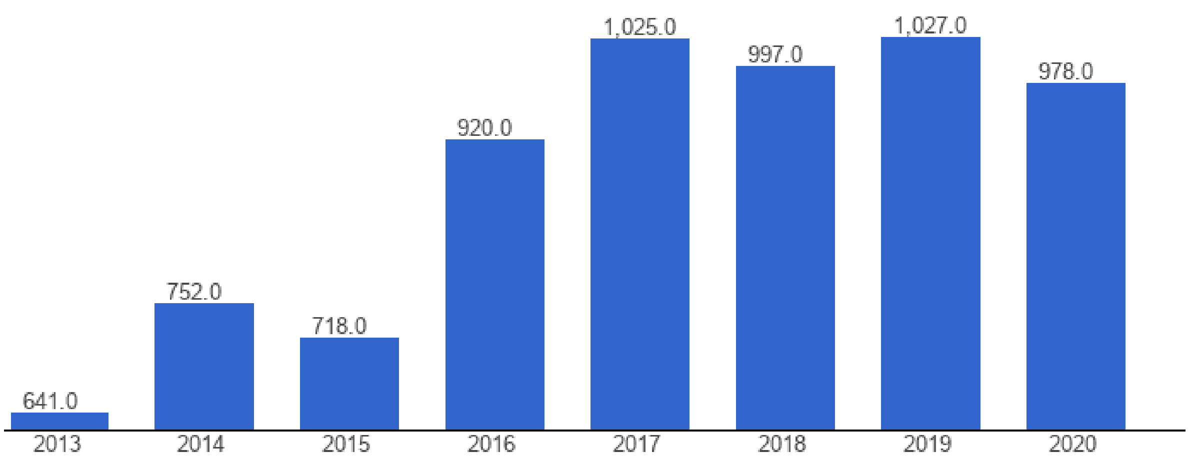


Figure 6: Patents applications over the previous years

According to all of these statistics and data, Egypt needs to shift from a resource-based economy to a knowledge-based economy that encourages innovation and the search for new technologies to boost productivity and efficiency across a wide range of industries. One industry that has the potential to increase crop production and spur economic growth is agriculture, which employs a sizeable portion of the population. By implementing new, developing technologies like remote sensing, IoT sensors, and AI-based decision support systems, for example, crop production could be increased. But, in order for the Egyptian governments to benefit from this transition, they must first determine where the issue originates—from people, markets, policy, culture, finance, or infrastructural support—and then put the appropriate policies in place.

Causes:

Research and development investments:

The purchase of Environmental improvement and economic progress depend heavily on research and development. It can stimulate the growth of human capital, bring in foreign direct investments, and result in the production of new ideas, innovations, and goods. Spending on R&D in Egypt amounts to just 0.9% of GDP, which is significantly less than the 1.7% average for the world. R&D investments are seen as a major engine of economic growth in many developed countries. For instance, the United States, one of the most developed countries, invests nearly 3.4% of its GDP in research and development, which is an essential (*Research and Development Expenditure (% of GDP) - World | Data*, n.d.).

Out-dated infrastructure:

Insufficient infrastructure in Egypt seems to be an obstacle to the development of the science, technology, and innovation sectors. The country has been struggling with energy shortages and frequent power cuts for years, which not only hinder economic activity but also the lives of its citizens. Furthermore, the inadequate information and communication technology (ICT) sector plays a key role in the deterioration of Egypt's infrastructure. There are many evolving industries and businesses that rely heavily on access to reliable and high-speed internet. Egypt is currently ranked 86th worldwide with an average speed of 35.67 Mbps, according to the Speed Test Global Index 2022 (*Egypt Ranks First in Africa for Fixed Internet*

Speed in January 2022's Speedtest Index, n.d.). Logistics performance is also a weak point in Egypt's infrastructure, especially when Egypt ranks 67th in the Logistics Performance Index (LPI) Report 2018 (*Logistics Performance Index*, n.d.). Egypt's transportation networks are often congested and unreliable. This can make it difficult for businesses to transport goods and for workers to commute to their jobs, which can ultimately slow down economic growth. Overall, Egypt was ranked 93rd out of 132 countries in the Global Innovation Index Report 2022 in terms of infrastructure (Soumitra et al., 2022).

Lack of entrepreneurial culture:

Egypt's potential to expand its STI industry is significantly influenced by the business environment in that country. Egypt is ranked 114th out of 190 nations in terms of how easy it is to conduct business, according to the World Bank's Doing Business 2021 report. This shows that the country is facing severe barriers to entrepreneurship and innovation. In fact, young people in Egypt aren't aware of entrepreneurship and see it as a risky path. So, governments must thus launch programs and initiatives to educate young people about the value of entrepreneurship and its positive impact on the economy and living standards. (Bank, 2020).

Impacts:

Brain drain:

Talented people have left Egypt in search of better opportunities due to the difficulties facing the STI sector there, including a lack of funding, outdated infrastructure, and inadequate research facilities. Egypt has witnessed a rise in immigrant scholars working in Europe during the past ten years, particularly in the fields of medicine, engineering, and science. According to the Central Agency for Public Mobilization and Statistics, the number of Egyptian migrant experts and scholars is estimated to be 854,000, of whom 600,000 work in rare specialties. The total number of immigrants with a PhD is 66; the total number of immigrants with a master's degree is 164; and the total number of immigrants with a high school diploma is 119. According to these statistics and Figure (7), the majority of immigrants complete secondary school and are considered a human capital weapon for any country (Mahmoud, 2020).

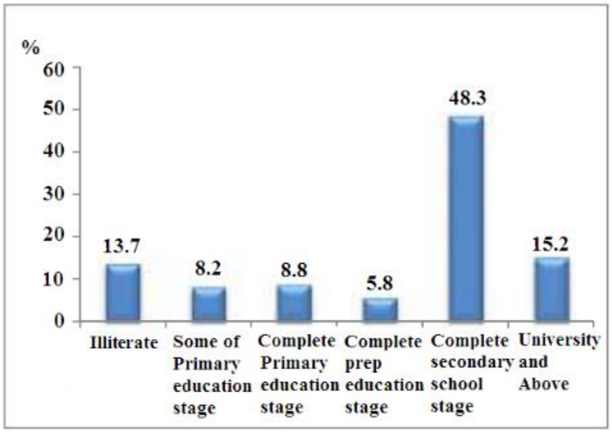


Figure 7: Brain drains in Egypt across Education levels.

Low productivity:

The lack of access to the latest technologies and innovations has led to decreased productivity in several industries in Egypt. In fact, with total exports of 26,815,144.69 US dollars and total imports of 60,279,553.52 US dollars, Egypt had a negative trade balance of -33,464,408.83 US dollars. Compared to a global growth rate of -3.91%, trade growth is -5.82%. This negative trade balance results from the traditional economy in Egypt, which depends mainly on resources without access to modern technologies or innovation practices (*Egypt, Arab Rep. Trade Statistics | WITS*, n.d.).

Lack of foreign direct investment (FDI):

Over the last decade, many foreign investors have avoided Egypt because they believe it to be unsuited for innovation and knowledge development. Egypt's environmental status has made it more difficult for it to draw in outside capital and diversify its economy. The World Bank reports that Egypt continues to have low levels of foreign direct investment, with inflows of only $5.12 billion in 2021, compared to numerous developed countries such as the US, which witnessed $448 billion in inflows. Even neighboring Middle Eastern countries like Saudi Arabia and the United Arab Emirates have received significant foreign direct investment, with each receiving $20 billion *(Foreign Direct Investment, Net Inflows (BoP, Current US$) - World | Data, n.d.).*

Industrial and Agricultural bases

Overview:

The downfall of industrial and agricultural bases since the uprising in 2011 has shown severe strains on the available resources in Egypt (Khan & Miller, 2016). Not to say, the requirements for resources are steadily increasing. Because of the current population, 105 million people, and the annual increase of 1.9% as shown in Figure (8) (*Population Growth (Annual %) - Egypt, Arab Rep. | Data*, n.d.).

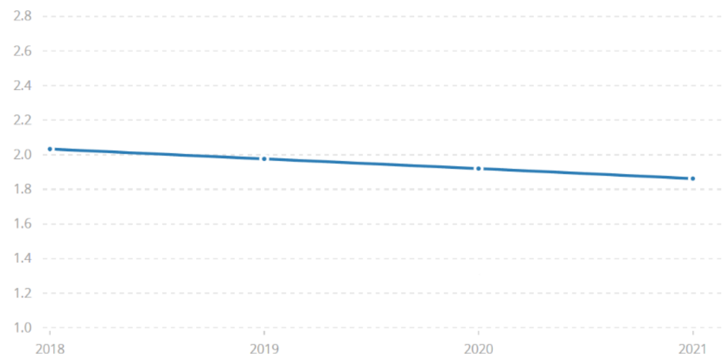


Figure 8: Annual population increase from 2018 to 2021. (Population Growth (Annual %) - Egypt, Arab Rep. | Data, n.d.)

Evidently, Egypt's gross domestic product (GDP) is suffering, as in Figure (9) (*GDP Growth (Annual %) - Egypt, Arab Rep. | Data*, n.d.). The regress in Egypt's industrial and agricultural bases can be largely blamed for the current status in the economy, since they contribute about 11.3% and 30.7%, respectively, to the country's total GDP (*Agriculture and Food Security | Egypt | U.S. Agency for International Development*, n.d.; *Egypt - GDP Distribution across Economic Sectors 2011-2021*, n.d.). As a result, Egypt has emerged as one of the major importers of industrial and agricultural products, especially in food, as Egypt is currently the largest wheat importer in the world, with estimated importers reaching 12.5 MT of wheat for the current marketing year (*FAO GIEWS Country Brief on Egypt* -, n.d.).

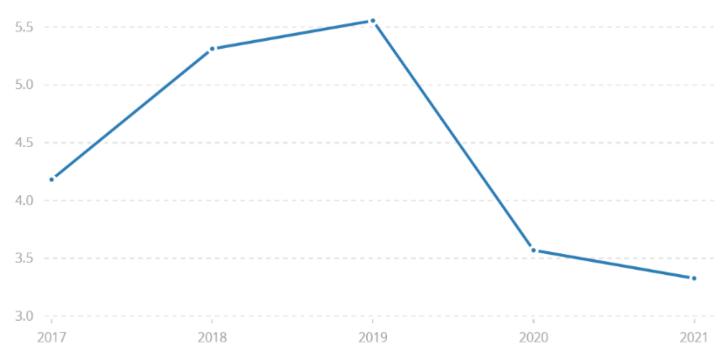


Figure 9: GDP growth (2017-2021). (World bank)

One the other side, in 2019, Egypt imported around 13.6 billion USD worth of electrical and industrial machinery. Not to mention that industry operates on agricultural materials, so the connection between the two bases in undeniable. This means that the situation in one base is affected by the other.

Causes:

Arid areas:

In Egypt, over 90% of the population inhibit the land directly near the Nile River, which composes around 5% of the Egypt's total lands, with the other 95% being part of the deserts(Yumna et al., 2018). Such unequal distribution in population makes industrial activity disappear in most areas of Egypt, thereby, limiting the Egyptian industrial development and the exploitation of natural resources.

Egypt's total fertile lands amount to 3.3 million ha, one quarter of which are reclaimed from the desert. However, the reclaimed lands add only 7% to the total agricultural production. Even though 3% of Egypt is arable, agricultural productivity is limited by salinity, afflicting an estimation of 35% of cultivated land, and drainage issues.

The fact that over 96% of Egypt's lands have no value whatsoever to the agriculture greatly limits the options and questions the agricultural productivity of Egypt as a whole. In fact, the lack of fertile lands causes Egypt's most populated cities to have low-to-none agricultural activity, as shown in Figure (10) (El-Ramady et al., 2013).

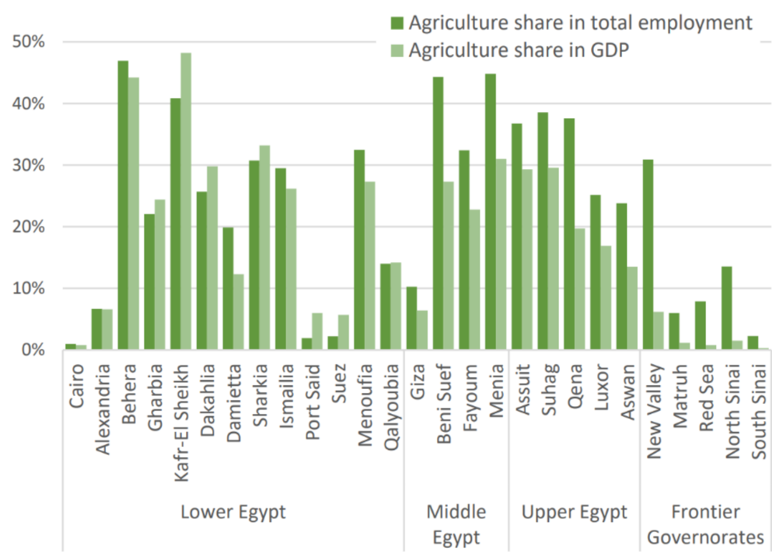


Figure 10: Distribution of agricultural share in employment and GDP on Egyptian cities. (El-Ramady et al., 2013)

Climate change:

Agriculture has been and will always be the most affected by climate changes where crop productivity will be affected through increased evapotranspiration demand and direct heat stress. The same goes for livestock and fisheries due to the climate change-induced changes in water quality and feed availability. (Perez et al., 2021)

The arable land near The Nile River is particularly sensitive to increased sea level and precipitation, and to temperature change. Many postulations about the impact of climate change on farming include the following: a decline of 30-40% in agricultural productivity and consequent reduction in farm net revenue, increased water consumption for crops, soil degradation, lost agricultural lands, and internal migration from vulnerable lands, near the Nile Delta, to other areas. (Kassem et al., 2019)

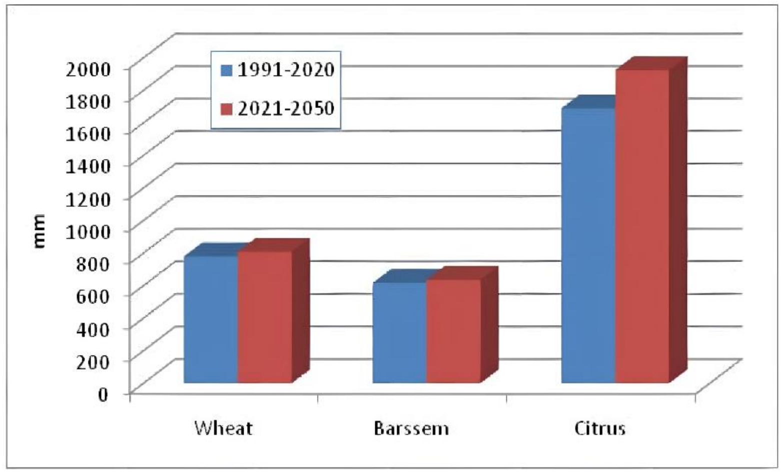


Figure 11: Crop water requirement under current and forecasted climate conditions. (Makar et al., 2022)

Such impacts were reflected on the 2012-2015 period where a temperature increase of 2°C caused production reductions of 18%, 18%, and 11%, for barley, maize, and rice, respectively (Kassem et al., 2019). Also, water requirements for many crops are expected to change. For example, Figure (11) shows the difference in crop water requirements between current and forecasted climate conditions (Makar et al., 2022).

Water scarcity:

Egypt has reached a state where the quantity of water available is imposing limits on its national economic development. As indication of scarcity in absolute terms, often the threshold value of 1000 m3/capita/year, is used. Egypt has passed that threshold already in the nineties. As a threshold of absolute scarcity 500 m3/capita/year is used, Egypt will reach this level soon, considering the population projections for 2025.

In addition, the industrial sector in Egypt consumes about 12.6 billion cubic meters of water annually, which accounts for about 17% of the total water consumption in the country. Due to water scarcity, however, many industries in Egypt have been forced to lower their usage of water of shut their operation down. That’s beside the suffering of the agricultural sector, where irrigation accounts for about 85% of the country’s total water consumption.

Impacts:

Unemployment:

With the downfall of the agricultural and industrial bases in 2015, many people lost their jobs, accompanied by the decrease in GDP where the unemployment and GDP growth rates reached 12.9 and 4.2, respectively, as shown in Figures (12.a & 12.b). In addition, the youth unemployment percentage reached a staggering 35% in 2015. (Khan & Miller, 2016)

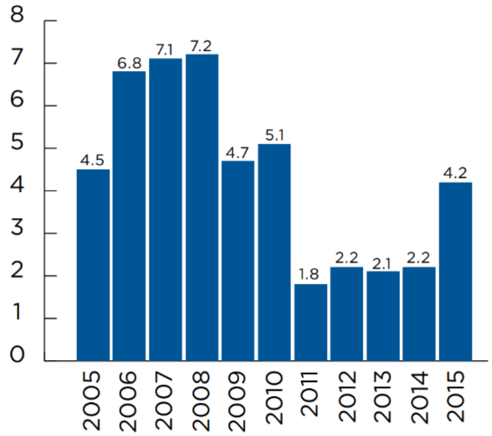


Figure (12.a). GDP growth in percentage.

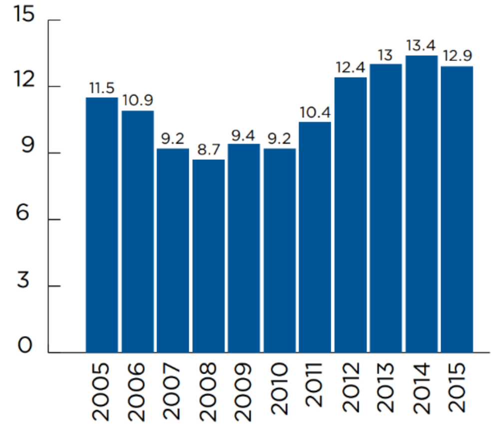


Figure (12.b). Unemployment in percentage

(Khan & Miller, 2016)

Economic recession:

The unproductivity of agriculture and industry is put to question with the amount of imports entering the country. The country's name is currently present as one of the top imports in many products, whether agricultural or industrial. Egypt is the second largest importer of cereals after China by spending over 7.17 USD billion on cereals. The difference between imports and exports puts the country into a severe economic recession with a total of imports 78.6 USD billion and total exports worth of 30.6 billion, giving the country a trade balance worth of 48 USD billion.

Unfortunately, the trade balance causes a great price inflation, especially on food prices, and consequently, a decrease in the country's reserves. The annual food price inflation was estimated to be 22.4% in 2022 due to strong international commodity prices and a weakening currency. On the other side, with the weakening of the currency, the country's reserves, which were estimated to be 40.8 USD billion, have dropped down to 33.14 USD billion.

This mainly spreads poverty among the Egyptian population where, according to the latest world bank figures, 20% of the Egyptian population is below the national poverty line and another 20% of Egyptians are considered to be near poor, and this mainly affects those affiliated with the agricultural sector that represents around 40% of the Egyptian workforce.

Hunger:

Egypt faces a long-term threat to food and water security. The population is booming, and its food needs are on the rise, but Egypt has a declining resource base. Egypt has limited water resources because it relies mostly on Nile water by 95% where any decrease in the amounts of Egypt's water share will lead to the deepening of the food security gap and is expected to increase to 70%. (Mohamed, 2019)

The coping of water scarcity in Egypt is not an easy matter due to the high population growth, limited water and land resources, and the problems with upstream Nile rivers especially after the mega dams constructed in Ethiopia. (Mohamed, 2019)

Egypt's agricultural sector currently uses 86% of the nation's water supply, yet domestic production levels are considerably short of the demand and do not exceed 40% of the Egyptian needs. Two third of the 18.8 million tons of grains that Egypt consumes annually is imported, making it the world's largest grain importer. In total, Egypt imports 60% of its total food needs. (Mohamed, 2019)

All of that happen accompanied by the influenza epidemic in 2006, the global price increase in 2010, and the uprising in 2011, causing an astronomical increase in prices. As a result, significant pockets of poverty and food insecurity are emerging in urban areas, where poverty increased by nearly 40% between 2009 and 2011 (the national average of poverty increased to 27.8% in 2016 in addition to 5.5% of chronic poor).

In addition, the poor sanitation in rural areas (reaching 65% of households) along with the scarcity of access to health services (reaching 23%) and bad living standards create a type of poverty that has many aspects and dimensions. In urban areas, the weak health services (reaching 27.4%) contribute the most which urges a need to invest in basic services (Mohamed, 2019). Consequently, according to a UN World Health Organization study in 2011, it was found that 31% of Egyptian children under the age of 5 suffer from stunted growth. It was also found that 16 percent overweight and/or obesity rate, and 5.5 percent underweight rate are found in children under the age of 5. (*Egypt | World Food Programme*, 2011.; Thelwell, 2020)

Recycling

Overview

Recently, Egypt and other developing countries have started to face a variety of environmental challenges that require the awareness of sustainable waste management needs. Waste management can be achieved through different methods, including recycling, landfill, bioremediation, and composting as shown in Figure (13) (World Bank, 2018). Recycling aims to conversion of waste materials, which can be produced from different industries, into usable products that can be used for various industries. The collection of waste materials and processing are the steps of recycling of used materials or wastes. The practice of recycling can achieve resource conservation, pollution decrease, and waste reduction. Therefore, it affects the environment and the other related aspects positively. There are many forms of recycling, including chemical recycling, mechanical recycling, and biological recycling.

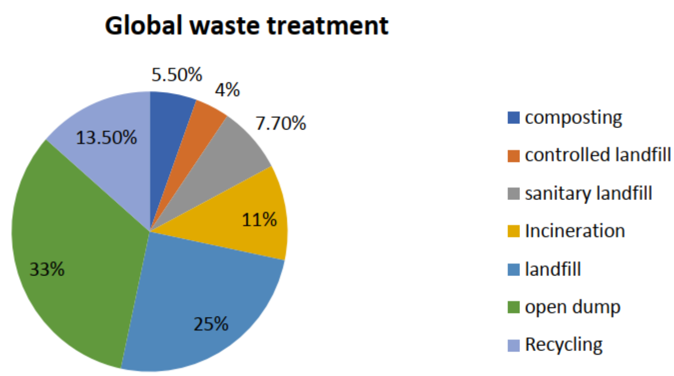


Figure 13: World Bank (2018), the different methods of waste

Egypt suffers from a high rate of population growth, as well as, rapid urbanization, which implies an increase in the consumption of materials. According to the world bank, in 2012, Egypt generated nearly 90 million tons of agricultural waste, construction and demolition debris, municipal solid waste, and other industrial wastes. About 47% of the solid waste is produced from facilities that are in Greater Cairo Governorates, Cairo, Giza, and Qalyubia. Only 12% of household solid waste is recycled and the remaining waste is disposed either randomly or in sanitary landfills, (Hashem, 2020). However, the average global recycling rate for municipal solid waste is approximately 32%, as mentioned by (Kaza et al., 2018). The low rate of recycling in Egypt is due to several causes, involving the infrastructure, low income, and the low awareness of sustainability importance. Consequently, the improper waste management results in various impacts that affect the environment, resource conservation, and public health negatively.

Causes

- ***Economic factors***

The high cost of recycling operations compared to the low value of the recycled materials decrease the chance of investigation in recycling sector in Egypt. The economic status affects significantly waste management methods as shown in Figure (14). Countries that have low income depend on disposing wastes in the streets or in the landfills, implying that recycling operations are relatively high. High income countries, however, do not depend on recycling completely due to the high value of the operation and the low profit of the recycled materials. The problem is that recycling depends on collecting wastes, sorting them according to their type, processing, and transporting.

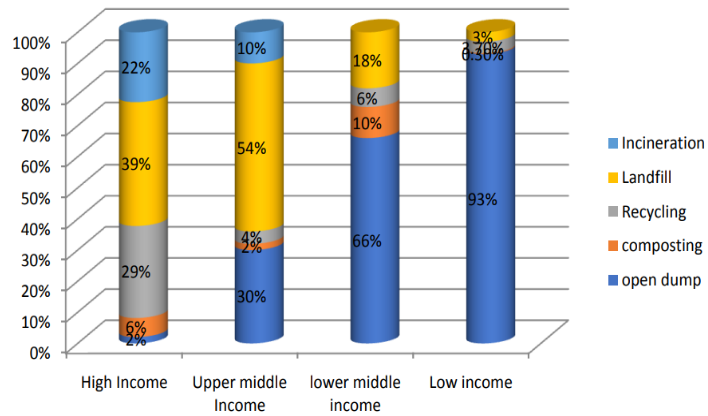


Figure 14: Effect of economic factors on waste management methods.

- ***Energy consumption***

Converting wastes into new, usable materials requires processes that uses high amount of energy. Additionally, the operations depend on the content of the material. For instance, the recycling of metals requires about ten times more energy than the recycling of paper; it depends on the operations that are performed, as well as the composition of the matter. For example, plastic needs to be recycled using 88% less energy than the production of the new plastic as stated by the American Chemistry Council. Further, the recycled aluminum saves about of the 95% of the energy that are consumed in the process of converting bauxite ore into aluminum, according to the United States Environmental Protection Agency.

- ***The lack of necessary Infrastructure***

The current infrastructure of Egypt is not suitable for recycling; Egypt has only about 25 recycling facilities, a number of facilities that is insufficient for the massive production of wastes throughout the year. Consequently, it is estimated by the Egyptian ministry of environment that about 60-70% of the wastes are collected in urban areas, whereas only 10-15% of the wastes are collected in the rural areas. Hence, the infrastructure of Egypt is not sufficient for applying waste management processes.

Impacts

- ***Environmental impact***

About only 12% of the household solid waste is recycled, while the remaining is disposed into the streets and landfills. As Egypt produces about 90 million tons of wastes annually, about 79.2 million tons of wastes are exposed to the open dumping, resulting in decomposition of organic wastes, which represent about 56% of the solid waste as shown in Figure (15). Moreover, the decomposition of the organic waste leads to the synthesis of methane and CO_2 that contribute to the climate change. In addition, disposing of wastes or the open dumping causes damaging of the environment.

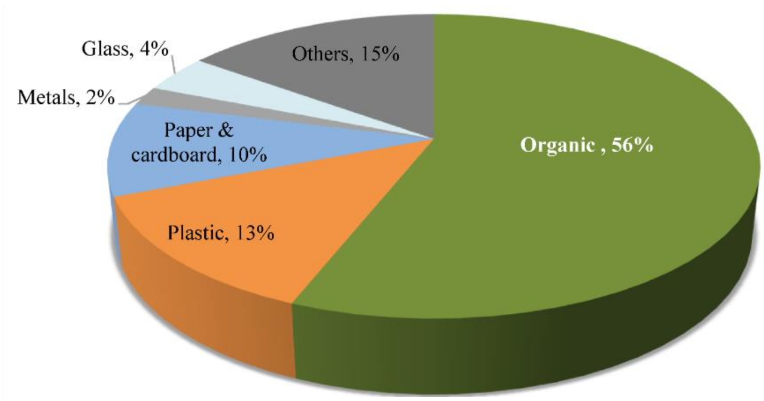


Figure 15: Percentage of different waste types.

- ***Economic effect***

Recycling requires collecting wastes and sorting them, indicating that many job opportunities can be available. As the recycling rate, in Egypt, is low, these job opportunities are not available. Moreover, it can contribute to conserving of materials and decrease the contaminates that result from the production of these materials. For instance, recycling of aluminum can save about 88% of the energy.

1.2: Problem to be Solved:

Resources Unsustainability in Agriculture due to Traditional Farming

Agriculture is one of the main economic activities with a GDP contribution of about 11.83% in 2021. Further, global food demand is predicted to double by 2050. Hence, sustainable agriculture is considered one of the essential goals to maintain a consistent nutritional supply for future generations and is strongly linked to solving Egypt's Grand Challenges and achieving the United Nations Sustainable Developing Goals. On the other hand, current practices in farming sectors, including overexploitation and chemical fertilizing, are suffering from several issues hindering their efficiency and making them susceptible to environmental concerns.

For instance, overproduction of monoculture crops often leads to increased soil degradation. Growing only one variety of crops in each space possible can highly impact the concentrations of nutrients in soil. In fact, iron, zinc, and phosphorus are among the scarcest nutrients found in plants from Egyptian fields. Thus, growth is negatively impacted, and speculations show that the percentages of these micro-nutrients would reach less than 0.1% if sustainable practices were not followed in the next years.

Further, chemical fertilizers have been recently used in large quantities to support continuous growth of crops. This has significantly contributed to soil acidification and soil crust. In fact, negative effects of chemicals on soil pollution inhibit the absorption of several important minerals, including phosphorus, which increases the issue severity. Other issues include diminishing organic matter, humus content, beneficial organisms, hindering plant growth, changing soil pH, increasing pests, and even contributing to greenhouse gas emissions.

Although sustainable farming is associated with several advantages, including 10 times more long-run profit, 56% energy saving, and 64% greenhouse emission reduction, unsustainable practices are prevalent for several reasons. These include lack of action from policymakers, and more importantly, lack of immediate benefits. Sustainable agriculture can often be more labor intensive and require significantly more costs, which leads to less investment in sustainability projects and lack of serious efforts.

Subsequently, finding a cost-effective method to treat the lack of nutrients for plant growth while recycling wastes can significantly contribute to increasing the sustainability of agriculture. Hence, our problem to be solved is the unsustainability of resources consumption in agriculture, including nutrients consumption and waste recycling. As will be shown, solving this problem can have substantial positive outcomes. Failure to solve the problem, on the contrary, will have a significant impact on increasing the severity of other issues and impeding long-term sustainability and development plans.

Positive Consequences:

- ***Increasing Farming Efficiency and GDP:***

Providing a way to sustainably farm crops would result in higher yields while not affecting the soil's capability of supporting additional crops. Further, successfully recycling waste for utilization in agriculture would result in more effective utilization of resources for farming. This results in increasing investment in agricultural projects, and subsequently, agriculture could form a remarkable portion of the GDP. If sustainable practices were taken, GDP from agriculture could exceed 300 billion EGP in the next two years.

- ***Sustaining Food Resources at Low Costs:***

Success in following sustainable means of agriculture would achieve long-term food supply without affecting following generations. In fact, following sustainable practices would lead to more efficient resource usage, which implies cutting down the amounts of chemical fertilizers and pesticides applied to the soil. As a result, agriculture costs would decrease, leading to more accessible crop production with minimal costs. Hence, these means of agriculture would help achieve nutritional security.

Negative Consequences:

- ***Soil Degradation:***

Following unsustainable practices in agriculture would result in a decrease in soil quality and soil erosion due to chemical pollution, intensive overcultivation, and decreased soil protection. These lead to overall soil degradation, which has a negative effect on plant growth and quality. Soil degradation is expected to causes losses constituting about 10% of the GDP if not effectively solved.

- ***Water and Soil Pollution:***

Failing to treat nutritional deficiencies through sustainable methods would result in the continuous application of fertilizers and other chemicals that negatively affect soil and water. Abrupt changes in soil pH and mineral composition could take place, which may make the soil unsafe for crop growth. Moreover, nitrate leaching and polluted agricultural effluent can contribute significantly to water pollution and related phenomena such as eutrophication. Consequently, unsustainable practices would result in serious environmental pollution, leading to excessive losses in economics and health.

- ***Lack of Space and Resources:***

Traditional methods are considered prodigal in terms of space and resources. On the other hand, urban sprawling and rapid urbanization impose increasing space demand for residential and farming sites. Hence, failure to apply sustainable practices would result in excessive usage of space for farming to supply food demand, which would have negative impacts on climate and available space for urban regions.

1.3: Topics Related to the Problem

Nitrogen as a Form of Waste:

Nitrogen is one of the most essential elements for plant growth; it is the major component in proteins and other functioning living parts of the plant. On the other hand, several lands in Egypt suffer from nitrogen deficiency due to a variety of causes, most importantly lack of organic material since about 96% of Egypt's land is arid. Further, over-cultivation encourages farmers to apply chemical fertilizers to compensate for the lack of nitrogen, which impacts plants and soil negatively in the long run; several components of the fertilizers, including nitrogen itself, leak into the soil and either accumulate in it or are carried away with agriculture drainage.

Subsequently, several issues are caused. Nitrogen is leached from the soil, a phenomenon called nitrate leaching, leading to the need for additional fertilizer amounts. Further, the accumulation of nitrates and phosphorus in disposal drainage leads to the formation of algal blooms in drainage sites, a phenomenon known as eutrophication, which leads to the termination of marine life due to increased decomposing activity, which takes up dissolved oxygen.

Furthermore, waste nitrogen is found in soluble ammonium form in fish waste as shown in Figure (16). Ammonium can be toxic to marine life. Fish farms in which waste disposal is not done correctly may have abnormal pH levels, which offsets the nitrogen cycle and leads to the accumulation of ammonium ions. Ammonia is toxic to vertebrates as $(NH_4)^+$ ions displace K^+ ions in the nervous system, leading to malfunctioning. Concentrations as low as 2000-4500 ppm can terminate fish life rapidly.

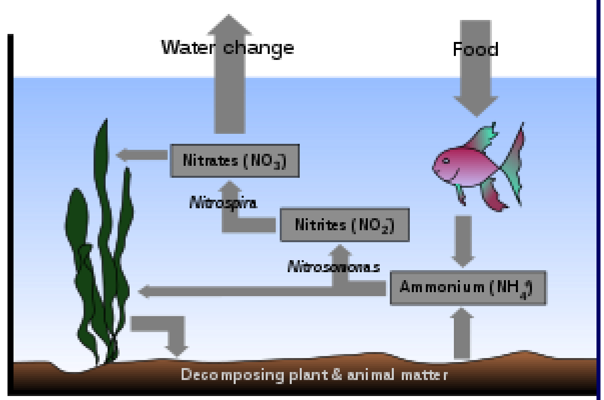


Figure 16: The nitrogen cycle in a typical marine environment.

Labor-intensive Activities and Technology Unavailability:

Following unsustainable and traditional farming practices is associated with increased labor and decreased productivity. The costs range between 15-35% of total farming costs. Further, labor-intensive practices are not suited for ultra-large production rates since they would require much space leading to deforestation, and costs would increase rapidly.

Traditional farming is still the prominent farming method for half of the world's population. However, it has several negative effects, including soil erosion and lack of eco-friendly practices. Although traditional farming has relatively low initial costs, it is considered ineffective for long-term investments.

On the other hand, automated farming and using of machinery represent a promising form of farming. However, the high initial costs associated with importing modern components and complex setups make this form of farming inaccessible to developing regions. Further, infrastructure issues, commonly found in underdeveloped regions, make automated farming susceptible to many performance issues, including power outages and malfunctions.

<u>Space deficiency:</u>

Most traditional farming practices do not utilize available space efficiently, which is associated with unsustainable resource consumption. About 5 billion hectares are currently used as farmland, shown in Figure (17). Compared with aquaponics, traditional agriculture utilizes about 6 times the amount of water to grow about only 1/8 of the food amount per acre, which makes it highly consuming. Further, horizontal row farming often utilizes inefficient irrigation techniques, and one kind of crop could cover a large area. These issues are often associated with nutritional deficiency and quality degradation.

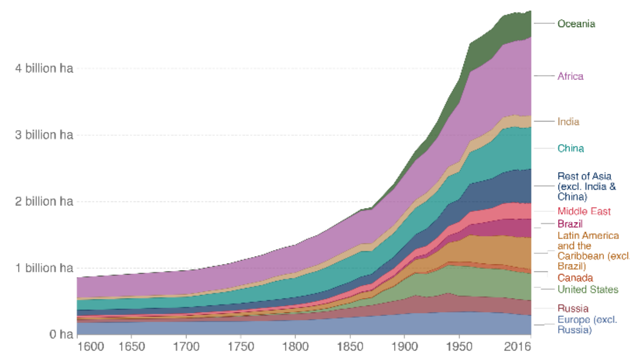


Figure 17: Agricultural area over the long-term, 1600 to 2016.

Excessive deforestation due to crawling of farmland can lead to several negative impacts, including increased carbon dioxide and other greenhouse gases concentration, more frequent natural catastrophes, and loss of valuable biodiversity.

Although space efficient farming methods exist, including vertical farming and aquaponics, their presence at an industrial scale is still limited, which makes the problem of space persistent.

1.4: Topics Related to the Solution

Soilless cultivation techniques:

Soil-based agricultural systems face various challenges due to climate changes, rapid urbanization, and the high rates of population growth all over the world. According to the United Nations, it is expected that the global population will approach approximately ten billion people by 2050. Moreover, about 66% of this number will live in urban areas. Accordingly, there is an increase in the demand for food and water resources, regardless of the current state of water scarcity and famine. The conventional use of arable land in cultivating crops in soils becomes increasingly difficult because of the limited areas of arable land as well as the high potential of these lands to be exposed to soil quality degradation. With 3.38% of its total land area, Egypt has a very small area of arable land as compared to the population, which is estimated to be about 107 million inhabitants, pointed out by the World Bank in 2020, as shown in Figure (18).

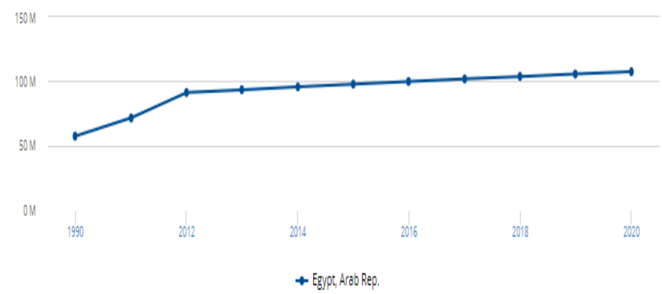


Figure 18: Total population of Egypt from 1990:2020

Soil, however, provides a suitable medium for plant growth; it anchors the roots of the plants, contains essential nutrients and minerals, and stores water depending on the needs of the plant. Although it poses these necessary factors, the different types of soil pose serious constraints to plant growth: inappropriate pH, salinity, poor drainage, low aeration, and the presence of pests and pathogens. Thus, cultivation in such a medium carries various challenges and threats to food security and public health. Also, water scarcity can be a result of growing crops in a conventional way, as some types of soil are characterized by excessive drainage, sandy soil, for instance. Figure (19) demonstrates the water withdrawal by the agriculture sector in Egypt. In addition, the pathogens in the soil can be responsible for water pollution.

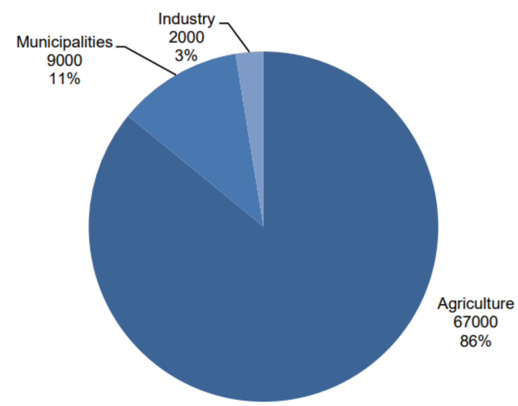


Figure 19: Water withdrawal by different sectors in Egypt.

Soilless cultivation has emerged as a promised alternative to the conventional way of cultivation. Instead of getting the nutrients from the soil, the plants get the appropriate amounts of nutrients from a nutrient-rich fluid. Considering the advantages of this solution, for example, the saving of water up to 85%, leads to applying various techniques, including hydroponics, aeroponics, and aquaponics.

Hydroponics are soilless cultivation systems that rely on introducing inert substrates instead of soil, or any aggregates, as illustrated in figure (x). There are two basic principles for applying hydroponics: closed system (continuous-flow solution culture) and open system (static solution culture). The first principle circulates the excess nutrient solution to be further reused, whereas the second one delivers the nutrients to the roots of the plants without recovering and recirculating the excess nutrients. It is possible to grow different crops in hydroponic cultures, providing optimal conditions for plant growth.

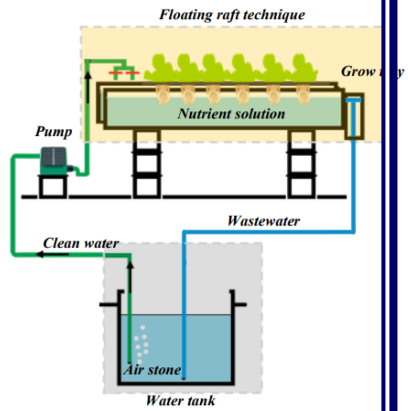


Figure 20: Scheme of hydroponic system.

Although the term “hydroponics” refers to a nutrient solution culture with no supporting medium, growing plants in solid media for anchorage using nutrient solution is also considered a type of hydroponics. It is called aggregate system, and it is demonstrated in Figure (21).

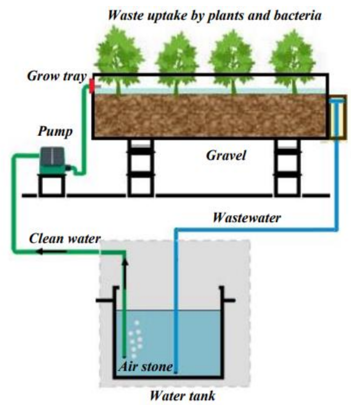


Figure 21: Scheme of aggregate system.

Liquid hydroponics includes a variety of techniques: Nutrient film technique (NFT), Deep flow technique (DFT), Root dipping technique, Floating technique, and capillary action technique. Solid media culture can be classified as open systems or closed systems. In the Aeroponic system, as shown in Figures (22.a & 22.b), the roots hang in the air and are misted with nutrient solution.

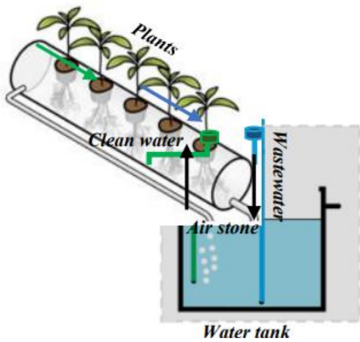


Figure (22.a): Demonstration of NFT

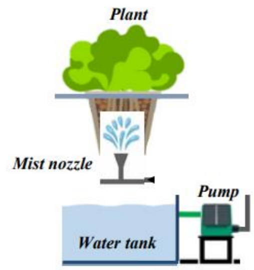


Figure (22.b): Illustration of aeroponic system.

Integrating fish and plants in a closed-loop system:

The hydroponic systems require expensive fertilizers for the growth of the plant. Replacing the fertilizer with an organic, cheap source of nutrients will contribute to achieve the sustainability. The composition of the fish waste, which include nitrogen, phosphorus, calcium, and other nutrients, can represent the role of the fertilizers. Moreover, using fish wastes can help in recirculating the water in water tank. Therefore, integrating fish and plants in a closed-loop system can serve as a solution for replacing the expensive fertilizers with cheap source of nutrients and for providing a valid environment for the growth of fish and plants. Integrating fish and plants in a closed-loop system is performed in aquaponics, as shown in Figure (23).

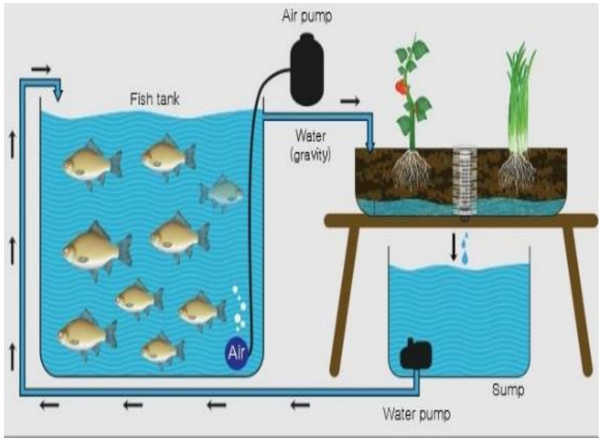


Figure 23: Scheme of the aquaponic

Aquaponics, also, depends on the decomposition of the ammonia, which results from the presence of fish excrement in the water. The decomposition of ammonia is performed by some species of nitrifying bacteria – Nitrosomonas, Nitrosococcus. After oxidizing the ammonia, it turns into nitrites, however, nitrites compounds are toxic for fish. Hence, aquaponic systems contain nitrifying bacteria species – Nitrobacter and Nitrococcus – that oxidize the nitrites, converting them into nitrates. Figure (24) demonstrated the changes in nitrogen levels in the

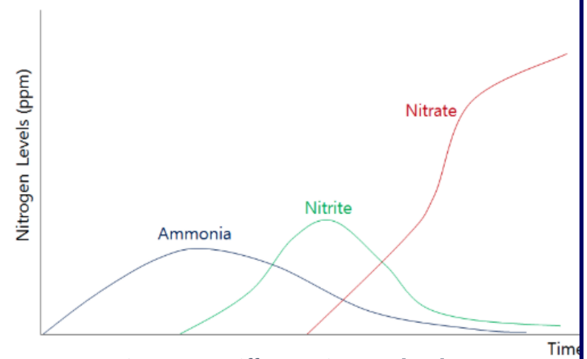


Figure 24: Different nitrogen levels over time (Baliga, n.d.)

water. The nitrates do not represent a source of toxicity for fish, indicating that the environment is valid for growth of fish. The aquaponics consume only 10% of the amount of water, implying that it can considered as a sustainable system for growing fish and plants.

The conversion of ammonia into nitrites, and then into nitrates can be demonstrated through the nitrogen cycle, in which three stages are performed consecutively, as illustrated in Figure (25).

Initial stage: After introducing the fish to the fish tank, excrement and the remaining food (uneaten food) are broken into ionized or unionized ammonia. The presence of unionized ammonia (NH_3) is toxic to the fish, even if the amount of unionized ammonia is only about 2 ppm.

Second stage: Nitrosomonas bacteria converts the ammonia into the form of nitrites by oxidizing it. The nitrites are toxic to the fish, because it combines with the hemoglobin, forming methemoglobin. Methemoglobin cannot carry blood through the body.

Third stage: Nitrobacter and Nitrococcus bacteria species oxidize the nitrites, turning nitrites into nitrates. The nitrates are not toxic for the fish, and the plants uptake the nitrates as source of nitrogen, that plays a crucial role in chlorophyll synthesis. The uptake of nitrates by the plant contributes to cleaning the water. Then, the water can be recirculated, and further nitrogen cycles can be performed.

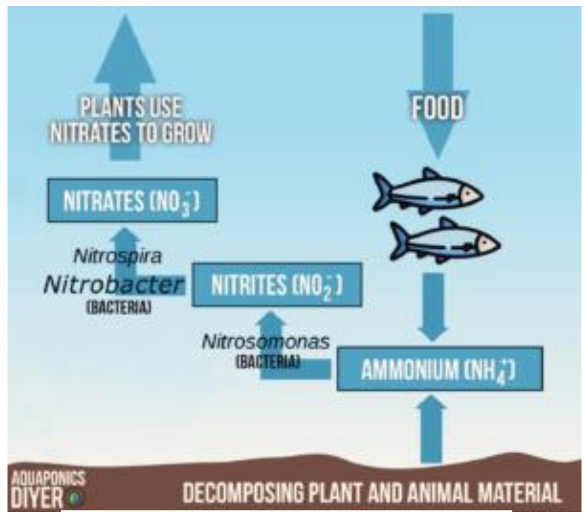


Figure 25: Aquaponic nitrogen cycle

1.5: Prior Solutions

Robotic Harvesting System with Visual Feedback System, UK

Mechanism:

A robotic platform called Vegebot has been developed in 2018 by various engineers at Cambridge University. Vegebot was made to address the harvesting challenges associated with sensitive plants, such as iceberg lettuce. The robotic platform uses Convolutional Neural Networks (CNNs) in order to locate, classify, and correctly harvest lettuce. The robotic system has been made to support harvesting in various fields by being a relatively low-cost system that is composed of off-the-shelf CNNs, a laptop computer, and ordinary webcams to collect information as well as mechanical components to perform the harvesting process.

Vegebot is constructed of a laptop computer running control software, a standard six-degree-of-freedom (DOF) UR10 robot arm, two cameras, and a custom end effector. All of the components are housed on a mobile platform for field testing as shown in Figure (26).

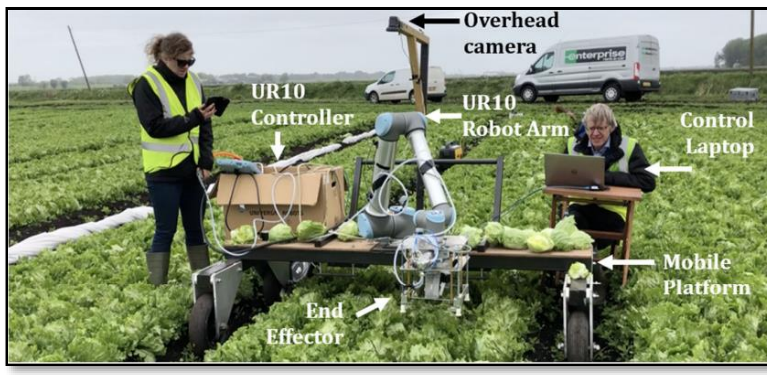


Figure 26: Vegebot operating during a field test.

The robot has been trained using different data sets in order to face issues associated with harvesting; since there could be unseen obstacles, a forced-feedback system has been implemented to measure elevation from the ground and the height at which the stem of the plant is cut. Corrective measures are taken immediately to position the knife blade attached to the device at the right height. A schematic diagram of the robotic systems is shown in Figure (27).

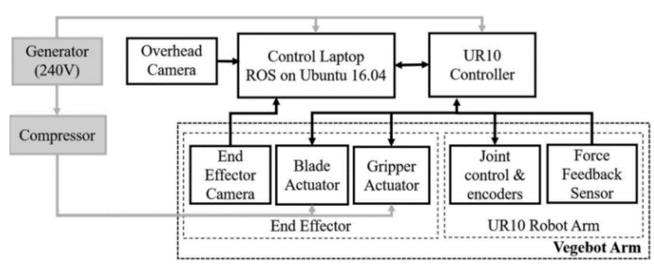


Figure 27: Schematic block diagram of the robotic system.

The robot also uses a feedback mechanism using AI networks in order to determine whether the object in front of it is lettuce (or any other specific plant) and determine whether it is ready to harvest or not. While harvesting lettuce, the robot receives feedback on whether the cut part contains an extra stem, leaf, or any other undesired part of the plant, and proceeds accordingly to cut the plant according to market quality standards.

The robotic system was able to harvest lettuce in various fields with a success rate of 88% and an average cycle time of 31.7 seconds per lettuce. The platform was able to harvest about 70 lettuces in one trip (Birrell et al., 2019).

Strengths:

- High harvest success rates and cycle time compared to that of humans (about 10 seconds).
- Usage of relatively available materials, including low-cost webcams and a normal laptop computer, and not depending on high-cost, specially prepared components.
- Little deviation with an average of about 1.5 cm between actual data about plant parts and observed data.

Weaknesses:

- High damage rate of about 38%, which means that a remarkable percentage of lettuce has been harvested while being in an unsaleable condition.
- Although major parts of the robotic system were made using cost-effective materials, the robot cost is still too high, preventing commercial applications.
- If the robotic system falsely identified an object as being a target plant, for instance, a human's hand, both the robot and the object could be harmed severely. Hence, the robot cannot classify ambiguous cases as being lettuce to prevent harm, which leads to a decrease in both safety and harvest rate.

AquaMaof Salmon Project

Overview

AquaMaof Salmon project, shown in Figure (28), is a project that is located in Poland, depending on two major principles: RAS System, Recirculatory Aquaculture system, as well as IMTA, Integrated multi-trophic Aquaculture. It depends on a feedback system that consider the water parameters of the aqueous environment. RAS is a system that recycle and reuse water after it has been exposed to mechanical and biological filtration and suspended particles removal. This technology is specialized for high-density culture of various species of fish. It utilized minimum land area and water. IMTA is an integration of two or more organisms, where they are farmed together. Multiple aquatic species from different trophic levels are farmed in the same tank to achieve the highest possible efficiency and reduce waste. Lower trophic level species – plants or invertebrates – depend on waste products as nutrients. Thus, IMTA achieve various targets simultaneously. AquaMaof Salmon project is implemented by AquaMaof company. In addition, it can produce about 4,000 tons of salmon annually, since it has been opened in 2018.

Figure 28: AquaMaof Salmon Project

Mechanism

The AquaMaof Salmon project depends on two different systems in order to achieve the highest quality of production. The first system is the RAS system, which is a closed-loop system that prepares the water in the tanks for reuse. Hence, it reduces the water consumption and achieves a sustainable system. The RAS system includes a group of biological and mechanical filters, resulting in wastes and excess nutrients removal from the tank. Also, a feedback system is incorporated into the project to monitor and check the parameters of the aquaculture, including pH, temperature, and dissolved oxygen. The feedback system collects and interprets the date that sensors have measured. The data analysis is done by a connected network of computers that can observe the changes in the environment and adjust these changes. Algorithms are responsible for the previous processes of the control system. The AquaMaof system is constructed by interconnecting tanks, each tank is designed for its own specific purpose.

The first tank includes fertilized eggs, where they are allowed to develop into young fish. After this, young fish are moved to next tank, the nursery tank, where they are farmed until they are large enough. The grow-out tanks are designed to be the largest environment, where integrated multi-trophic aquaculture is implemented. Each tank is provided with a group of sensors to monitor the key environmental factors that can affect the quality of the production.

Strengths

- ***High efficiency and efficiency***

  AquaMaof Salmon project achieves high efficiency as it depends on the integrated system that are more efficient than traditional monocultures. The integrated system can produce higher yields of aquatic organisms due to the presence of various organisms in the same aquaculture. The presence of different species can lead to the optimize the water quality as the IMTA include some invertebrates and plants that feed on the wastes of the higher trophic species. Thus, AquaMaof utilizes the RAS system that reuse the water to reduce the pollution and optimize the efficiency. The AquaMoaf can produce up to 4,000 tons of salmon per year.

- ***Sustainability***

  Depending on RAS and IMTA simultaneously results in a sustainable system. For instance, fish feed on the plants in the tanks. Additionally, wastes of fish represent a source of food for a lower level trophic organisms such as invertebrates. Moreover, the reuse of water in the tanks represents a real solution for the lack of water resources, which represent a serious challenge for most developing countries.

- ***Input costs reduction***

The AquaMaof Salmon project represents a suitable environment for various species, because of the presence of different organisms in the same tanks. Furthermore, the higher-level trophic species feed on the lower-level trophic species. Also, the lower trophic level organisms depend on the wastes of the higher-level trophic species as a source of food. Thus, it achieves the reduction of input costs.

Weaknesses

- ***High capital costs***

The construction and operation of RAS system as well as the IMTA system requires high capital costs compared to traditional aquaculture system. This is because of the usage of various technological advances in order to achieve the highest quality. Although the AquaMaof salmon system targets the reduction of input costs, it requires high capital costs to operate RAS system, which is used for reusing water and providing a healthy environment for all organisms.

- ***Risk of Disease outbreaks***

The integration of multiple-trophic organisms is exposed for the risk of disease outbreaks, as all organisms are farmed together in the same artificial environment. The infection of one of the species can lead to an entire system infection, because of the reliance on all organisms in the food chain. Moreover, the infection can happen from each other or from outside sources since they are farmed in an artificial environment.

- ***Reliance on technology***

Operating the RAS system requires the usage of various technological advances in order to monitor the water parameters of the tanks, including pH, salts concentration, and temperature. The occurrence of any fault in the technological advances can lead to wide range of disorders. Consequently, it can result in system damage.

SmartFish

Overview:

SmartFish is a project funded by the European Union (EU) and was operated from 1 January 2018 till 31 December 2022. It was tested and implemented in several European fisheries and seas. Namely, Norwegian Sea, Barents Sea, Mediterranean Sea, Black Sea, West of Scotland, northern North Sea, Southern North Sea, Celtic Sea, Bay of Biscay, Kattegat, and Skagerrak. With an overall budget of near 7 million Euro, the project's objective is to develop, test and promote high-tech system for the EU fishing sector. (Cordis Europa, 2022)

These high-tech systems' goals are to optimize resource efficiency, improve data collection automatically, as shown in Figure (29), reduce the ecological impact of the sector on the marine environment. There are three main objectives for the SmartFish systems:

Figure 29: Testing light technology of SmartFish. (Cordis Europa, 2022)

1- Assist commercial fishers in making informed decisions during pre-catch, catching, and post-catch phases of the extraction process.

2- Provide new data for stock assessment from commercial fishing and improve the quality and quantity of data that comes from traditional assessment

3- Permit the collection of catch data automatically.

Mechanism:

The project developed a system for pre-catch size and species recognition for purse seine fisheries – based on optical and hydroacoustic technologies. SmartFish exploits and further develops existing technological innovations in machine vision, camera technology, data processing, machine learning, artificial intelligence, big data analysis, smartphones/tablets, LED technology, acoustics and ROV technology. (Cordis Europa, 2022)

SmartFish developed and implemented 9 technologies:

1- SeinePrecog 2- FishFinder 3- TrawlMonitor

4- NephrosScan 5- SmartGear 6- CatchScanner

7- CatchSnap 8- CatchMonitor 9- FishData

These technologies are divided based on their mechanism into 3 categories: monitoring system, species identification, analysis.

Monitoring system:

First, SeinePrecog. It's a system made of sensors used for pre-catch size and species recognition for purse seine fisheries based on optical and hydroacoustic technologies. The camera used for the fish size estimation and species recognition is called "UTOFIA". A size discrimination algorithm for anchovy was implemented by including acoustic and biological data from fishing trawls that targeted anchovy of large sizes. Thus, this technology could detect and point out sizes of anchovy ranging from 4 cm to up to 16 cm.

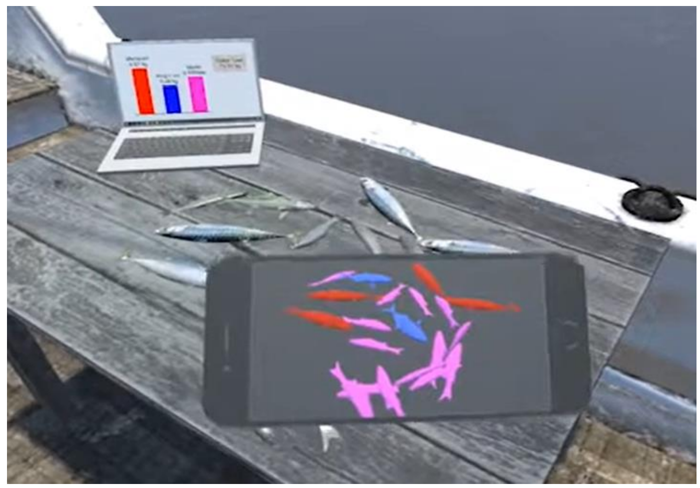


Figure 30: CatchSnap: 3D scanning and analysis of the data.

After the development of SeinePrecog, A prototype of a cable based real-time camera system, then developed a software to view and analyze the data collected by this cable, independent of UTOFIA 3D camera. Such was the development of the FishFinder technology which could deliver high quality images even in turbid water and could document both nephrops burrows and Norway lobster. Thus, the NephropsScan, as a technology, was specified only to detect nephrops burrows.

Finally, a cable-based 2D real-time monitoring system was applied on the trawls, which could detect the species entering the trawl and their sizes. This system is called TrawlMonitor.

Species identification:

Another line of work was focused on developing LED technology to optimize the catching process performance of trawl fishing gear. A programmable LED light pod with an acoustic modem was integrated using the reaction of fish to light. After several studies, SmartFish could change the fish behavior with the use of artificial light. With this new addition, it was possible to control the light settings from the wheelhouse. From this, SmartGear was developed to improve the catching performance of trawl fishing gear based on the reaction of fish to light. Also, the CatchScanner, which is a 3D machine vision system, was designed for deciding species of each fish categorized by cod, haddock, saithe or others. It was also responsible for estimating the weight and length of each fish. (Cordis Europa, 2022); *SMARTFISH H2020*, 2022.)

In addition, the CatchSnap enables 3D scanning using a mobile unit, a smartphone for example, to estimate the type, number, and species of the fish. Synthetic data sets, based on real 3D scans of fish, were used to train a deep learning system to encompass most types of species of fish. Figure (30) shows an example of the mechanism of CatchSnap. (French et al., 2020)

The last piece in the monitoring system is the CatchMonitor. It's a computer vision system that analyzes video from CCTV systems installed on fishing trawlers for the purpose of monitoring and quantifying discarded fish catch. This piece is responsible for monitoring the fish in fishing trawlers by image annotations, lens distortion correction and several other technologies, as shown in Figure (31). (Fisher et al., 2022)

Figure 31: One of the main phases of "CatchMonitor": Background removal. (Fisher et al., 2022)

Analysis:

SmartFish linked all the previously used technologies in a simple platform for the farms to access called FishData. It receives the data from the previous categories and analyzes them giving feedback for farmers through which the health and well-being of their fish stocks are presented. Also, the FishData platform allows farmers to optimize feeding regimes, adjust water

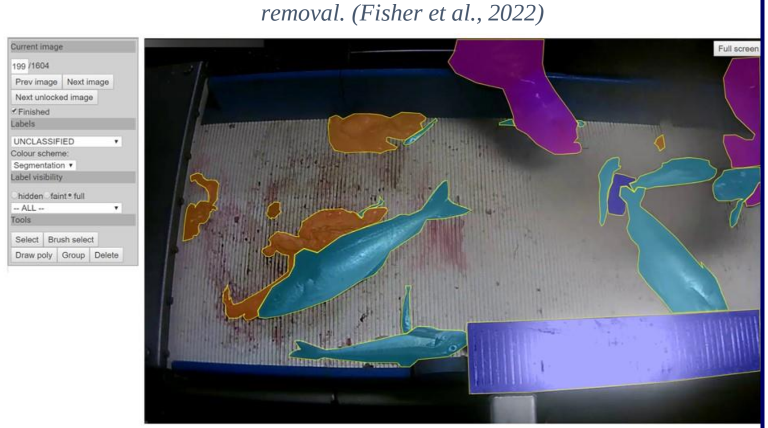


Figure 32: The final product of CatchMonitor. (French et al., 2020).

quality, and prevent disease outbreaks. By providing a data-driven approach for monitoring and controlling fish farms, FishData provides real-time monitoring and forecasting capabilities to support decision-making related to feeding regimes, disease management, and other aspects of fish farming. Figure (32) shows the final product of CatchMonitor.

Strengths:

1- Improvement of extraction process:

Improving catch efficiencies and compositions in fisheries across the EU leads to improvement economic efficiency while reducing unintended fish mortality. Also, assisting fishermen in making informed decision during pre-catch, catching, and post-catch phases of the extraction process.

2- large-scale profitability:

SmartFish generates fuel savings, reducing emission and operating costs. They can be categorized as 1- fuel saved from reduced mileage informed by pre-catch systems; 2- fuel saved from more effective sets informed by monitoring the catch process; 3- fuel saved from more efficient use of engines powering equipment. The total saving is estimated at 100 million liters of fuel, up to 5% savings for the EU fleet, unlocking savings worth € 75 million on fuel.

3- Accessibility:

All these technologies are complicated and can be quite intimidating for fishermen. However, linking all these technologies into a small interface for the farmers with many suggested decisions during the extraction process increase the favorability of fishermen towards this new project.

Weaknesses:

1- High initial cost:

Considering how complex the installation processes for these technologies and further linking them into a mobile platform, it requires indulge by professionals in the field, raising the total initial cost for the project. In addition, for the local fishermen, implementing such complicated technology in small sized businesses poses a great challenge economically.

2- Limited scope:

The project is only limited to fisheries in Europe and doesn’t take in consideration the other regions. Since SmartFish is specific to fisheries in Europe, it only focuses on few types of fish species that are not necessarily present in different fishing regions. It’s, also, worth noting that not all fishermen are suited for such advanced methods and may not have the ability to use them or even consider implementing them in their local fisheries.

3- Ecosystem disruption:

SmartFish eases pre-catch, catch, and post-catch processes of the fish extraction. This may seem an accomplishment. However, by easing out these processes, the amount of fish caught increases, and thus the ecosystems in oceans are disrupted by the decrease in fish numbers. A solution to that would be to introduce more regulatory laws to sustain the current environment and prevent its deterioration.

Chapter II: Generating and Defending a Solution

2.1: Solution Requirements

- ***Eco-friendiness***

Our world suffers from the consequences of pollution and climate change, both of which are considered disasters linked mainly to human activities. Wastes from various industries, including chemicals, have had an impact on air, soil, and water resources. As a result, the proposed solution for increasing industrial and agricultural bases and improving the technological environment must be eco-friendly; using hazardous materials would be hugely damaging and would lead to dismissal of the solution.

- ***Cost-effectiveness***

Many automated feedback systems have been previously developed, but their high costs prevent governments and institutions from implementing them. Hence, one of the factors that must be considered is the cost. A project must use cost-effective materials so as to provide the highest possible performance at the lowest costs. When the project's cost is high, it will discourage potential investors from implementing this solution.

- ***Availability***

The project's raw materials should be widely available and accessible. When raw materials are rare and expensive, a high chance exists that the project will not be widely implemented. As a result, the materials' availability is a critical requirement of the solution. This implies that materials used in the proposed solution should be available throughout Egypt for all regions, including the deserts and the Nile Valley.

- ***Efficiency***

The project's efficiency is controlled by a variety of factors, including outputs, inputs, and process time. Feedback systems should operate as efficiently as possible concerning resources and time. The proposed solution should be able to perform the required function while utilizing inputs wisely to reduce waste; efficiency is linked to the amount of energy and resources consumed. Therefore, when more energy is spent to complete a fixed task, the solution is considered less efficient and appealing.

- ***Sustainability***

The world suffers from major issues concerning resource availability and renewability. A successful solution must be a sustainable solution that can be implemented on a real-life scale without negatively affecting available resources for future generations. Thus, the solution must include almost zero harmful long-term effects.

2.2: Design Requirements

Temperature Range:

Temperature is an important factor in plant growth. Each plant species has a temperature range that is suitable for it. Varying temperatures contribute significantly to photosynthesis rates. Higher temperatures within the acceptable range often encourage shoot growth, particularly leaf expansion and stem elongation and thickness. Temperatures exceeding the ideal range, on the other hand, suppress growth. Further, temperature affects germination success; some plant seeds, such as lettuce and broccoli, germinate best in temperatures ranging from 13 to 21 degrees Celsius.

Henceforth, the temperature is an important parameter that should be monitored in each successful agricultural system. In order for the project to be considered successful, the temperature in the fish tank must be within recommended range for bacteria and fish growth, which is (23-27)°C.

pH Range:

pH, also referred to as hydrogen potential, is a common method used to describe the acidity or basicity of a solution using a logarithmic scale. pH can be calculated through Equation (1).

$$pH = -\,log_{10}[H_3O]^+$$

Equation 1: pH value for an aqueous solution.

Where $[H_3O]^+$ is the molarity of hydronium ions. Soil acidity has a significant impact on the solubility of minerals or nutrients. It is evident that the type and amount of vital nutrients accessible to plant roots are heavily influenced by soil conditions, where each plant has a specific pH range that should be maintained. pH impacts nutrient availability in the soil, and various plants have varied nutrient requirements.

In order for the project to satisfy the requirement of appropriate pH range. The pH must be maintained at 6.0–7.0 pH, which is optimal for lettuce growth since it makes most nutrients easily dissolved and readily absorbed by the lettuce roots.

Water Loss Percentage:

Water loss is defined as the amount of water that exits the prototype system during operation. In aquaponics, it is essential to ensure that water loss does not cause issues to the farmed marine life and that the project could continue working without running out of water. Water loss can be calculated using Equation (2).

$$(V_L)\% = \frac{\Delta h}{h_0}$$

Equation 2: Water loss percentage for project operation.

Where $(V_L)\%$ is the percentage of lost water volume, Δh is the change in water level, and h_0 is the initial level of water.

For the project to operate sustainably, the amount of water that could be replaced at once should not exceed 10% of the total water volume. Subsequently, water loss should not exceed 10% of the total tank volume for the project to be successful.

Estimated Water Pollution Potential ($\boldsymbol{EWPP}, \boldsymbol{\bar{\sigma}}$):

For the project to be sustainable and eco-friendly, it must have no negative long-term effects on the environment. An eco-friendly system is characterized by almost zero-waste operation and not contributing to pollution of surrounding media. EWWP is a scale measure that is used to quantitively describe how a project affects the environment during its runtime. Equation (3) is used to calculate EWPP.

$$\bar{\sigma} = \sum_{i=1}^{n} \frac{\sigma_i}{n}, \qquad \sigma = \frac{30 r_t}{Q} \times S$$

Equation 3: Estimated Water Pollution Potential.

Where $\bar{\sigma}$ is the EWPP. σ is the pollution potential coefficient for a specific polluting substance, r_t is the waste mass of the substance produced during one day of operation, Q is the permissible concentration of the substance multiplied by a volume of $1m^3$, S is a scale factor dependent on the substance toxicity and danger.

The value of EWWP usually ranges from 0 to 10 although it can have values outside this range. Values of 0 or less demonstrate environmentally perfect solutions, while values exceeding 10 represent polluting behavior. The project passes this design requirement if it achieves a value of 2 or less, which is considered permissible in agricultural contexts.

2.3: Selection of Solution

Current population trends and demand projections show the need for sustainable and robust approaches to agriculture and food production. About 30% of the World's arable land was lost in the last 40 years. Resources available for farming, including soil nutrients and fertilizers, have decreased and chemical alternatives were deemed unsuitable in the long term due to their harmful consequences. Further, available space has decreased significantly, which makes space management an important aspect of future planning.

Hence, it is critical to find a solution that replaces unsustainable practices found in farming while providing a method to utilize resources efficiently to maximize production and ensure nutritional security despite the accelerating demand. An impactful solution should recycle wasted materials as much as possible. Further, it should be as cost-effective as possible through the integration of structures and functions to supply needs with minimal required complexity and costs.

After conducting extensive research and examining previous studies, our chosen solution was the sandponics system using the Grow Bed Medium (GBM) approach. Our solution utilizes feedback mechanisms to monitor and automatically control different system conditions, which are water pH, temperature, and water lever. The sandponics system integrates aquaculture with hydroponics (cultivating plants in a water-based solution) while implementing sand as a growing medium for plants. The sandponics system forms a closed cycle of resources by converting fish waste into useful nitrate forms, which are supplied to the grow bed. The plants absorb the needed minerals, and the grow bed acts as a mechanical filter and biofilter for water. Microorganisms' activity in the grow bed converts organic matter into essential minerals, and the filtered water exits the grow bed into the fish tank to complete the cycle.

Why this Solution:

Sandponics represents a sustainable method to farm different types of plants while utilizing resources and space efficiently. Further, GBM produces about 8 times the amount of food per acre as that produced by traditional farming methods while consuming only about 1/6 the amount of water.

Moreover, GBM is more suitable for application in developing regions since its initial cost is relative. All types of crops could be efficiently grown in GBM, and the design and size could be adjusted in a flexible manner to suit nutrition needs in high-population areas. Sandponics following the GBM maximizes cost-effectiveness by using a widely available grow medium and recycling a great portion of wasted materials, including fish waste and dead plant remnants. The system utilizes waste ammonia found in fish waste, which is usually toxic and must be removed, and utilizes it as a valuable nitrogen source for plants by utilizing the biochemical processes of nitrifying bacteria.

In addition, many components of GBM systems could be recycled or replaced with available alternatives, making its construction more feasible. The sandponics system is characterized by low electricity consumption and does not need high technical experience to operate. The labor used is minimized as the automated feedback mechanism enables the system to operate continuously with minimal human intervention.

2.4: Selection of Prototype

The prototype revolves around a stand and two containers: a grow bed container and a fish tank, as shown in Figure (33). First, the grow bed container. It's a 64 cm x 30 cm x 34 cm plastic container. It's supported by a wood stand. There are three types of grow bed medium present in this container: fine sand, river rock, and expanded clay. The three media fill the container to a height of 30 cm. The three grow bed media are arranged vertically. River rock fills the lower 5 cm, the sand fills the other 25 cm, while the expanded clay is moderately spread over the surface of the sand. The grow bed container hosts 3 lettuce plants. A 2.5 cm diameter hole has been dug in its center to accommodate a bell siphon. A bell siphon, as shown in Figure (34), consists of three structures: standpipe, bell, and media guard.

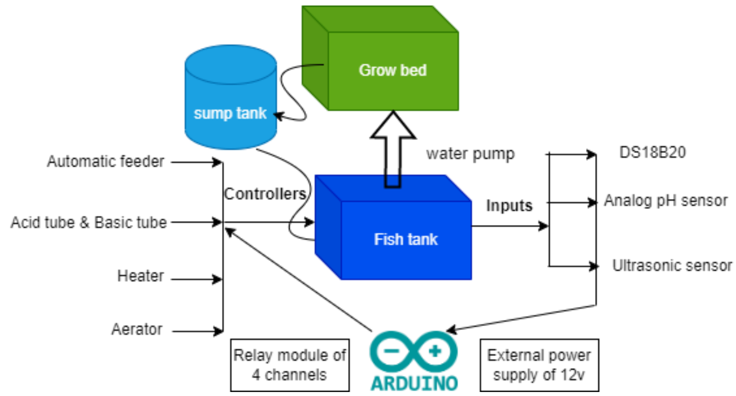


Figure 33: Prototype schematic.

Figure 34: Bell siphon

The standpipe, the most inner part, is a 2.5 cm diameter PVC pipe with a height of 24 cm. It has the same diameter as a hole to prevent any leakage outside the bell siphon's influence. The middle part – the bell – is also a PVC pipe and has a diameter of 5 cm height of 30 cm. The part that protects the other bell siphon's components – the media guard – consists of recycled polyethylene terephthalate (PET) plastic bottle.

The bottle features 7.5cm of diameter and 36 cm of height. Each of the media guard and bell has been opened at the bottom to allow the passage of the water in the bell siphon. These openings have been made smaller than the river rock – < 8 mm – to prevent their interference in the mechanism of bell siphon. Under the grow bed container, the bell siphon is connected to an elbow and a pipe to ensure the passage of air and the airlock. After the water drains through the bell siphon, it enters a sump tank that's then drained into the fish tank.

Second, the fish tank. The fish tank is a polypropylene (PP) plastic tank of dimensions 33 cm x 55 cm x 45 cm. The tank is filled with 67 liters to accommodate 290 grams of fish. The lid of the fish tank is where the technical system lies. Many holes were dug in the lid to accommodate the different sensors and controllers. The sensors used are water pH sensor, ultrasonic sensor – to sense the water level – and water-proof temperature sensor. They give signals for the Arduino Uno to give orders for the controllers: two mini water pumps, automatic feeder, and the temperature stabilizing system. The mini water pumps are used in the pH stabilizing system that consists of two pipes that hold an acid (H_2PO_4) and a base (CaOH). The automatic feeder consists of a servo motor and a container holding the fish food grains. The temperature stabilizing system consists of a PTC aluminum heater.

Chapter III: Constructing and Testing a Prototype

3.1: Materials and Methods

Name	Description	Quantity	Source	Cost (LE)	Image
Tilapia fish	Freshwater fish used as a nutrient source.	250 grams	Fish farm	---	
Red leaf lettuce seed	A fast-growing crop used as nutrient absorbent.	3 seeds	Agriculture Research center	10	
Analog pH sensor	Electronic device used to accurately measure acidity and alkalinity in water	1	Local supplier	500	
Waterproof temperature sensor (DS18B20)	Electronic device that measures the temperature of water.	1	Electronic store	900	
PTC heater	Electrical resistance heater used to maintain warm temperature for fish.	1	Electronic store	65	
Arduino Uno	Arduino UNO is a microcontroller board with 14 digital input/output pins and 6 analog inputs.	1	Electronic store	95	
Red wigglers worms	Composting worms for breaking down organic matter.	100 grams	Agricultural Research Center	20	
Mini water pump	An Electronic device used to circulate water in the system.	3	Electronic store	350	

Table 1: Materials list

Methods:

With the materials for the prototype assembled, the next step was to develop a clear methodology for testing and evaluating its effectiveness. The prototype construction passed through two phases: fish tank and hydroponic bed. A fish tank filled with 48 liters of dechlorinated water serves as a home for 290 grams stocking density of fish.

1- Constructing Fish tank

The lid of the fish tank serves as the "**brain**" of this prototype, as shown in Figure (35), where a microcontroller (Arduino Uno) was connected to breadboard that acts as a bridge to control all the following components:

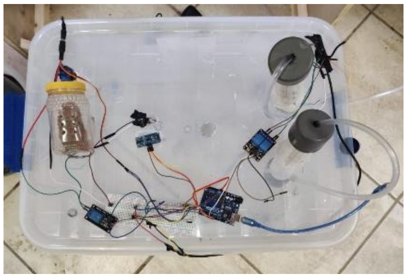


Figure 35: Lid of the fish tank

First, Pump-based pH control system:
An analog pH sensor was inserted into the fish tank, with three pins connected to the Arduino (VCC to 5V, GND to GND, and analog pin to A0). From signal to action, two pH tubes of volume 0.5 liter, one for calcium hydroxide ($Ca(OH)_2$) solution and the other for phosphoric acid (H_3PO_4) solution, were installed with two submersible mini water pumps. The pumps were controlled by a 3- channel relay module which was responsible for switching on and off them based on the pH sensor data. The acid and base pumps were connected to digital pins 7 and 12, respectively.

Second, Temperature control system:
A waterproof temperature sensor was submerged in the fish tank and connected to the Arduino's 5V pin for VDD, GND for GND, and digital pin 2 for signal (with a 4.7k pull-up resistor between signal and power). To control the temperature, a PTC heater is submerged in water and connected to relay module with external power supply of 12V and connected to Arduino via digital pin 4.

Third, A small-perforated plastic can, attached to a servo motor at its cap, as illustrated in Figure (36), was installed on the top layer of the fish tank to control fish feeding rate. An ultrasonic sensor was also embedded in the layer and connected to the Arduino via digital pins 9 and 10 (trig and echo pins, respectively) as well as to the 5V and ground pins.

Figure 36: Automatic feeder

2- Constructing Hydroponic bed:

First, a plastic container with dimensions of 70 cm length, 30 cm width, and 34 cm height was established above a wooden stand with a hole at its center. Through this hole, the water is drained through a constructed bell siphon. This bell siphon consists of 3 components, including media guard (36 cm height and 7.5 cm diameter), bell (30 cm height and 5cm diameter), and standpipe (24 cm height and 2.5cm diameter) shown in Figure (37).

Figure 37: Bell Siphon

Second, a three-layer grow bed medium was installed, with a height of 5 cm for gravel, 25 cm for sand, and moderately spread expanded clay on the surface. Finally, 0.5 kg of red wiggler worms were placed at the top layer of medium.

3.2: Test plan

1- The Arduino was connected to Laptop via cable. The heater was connected to an external power supply of 12 volts, and the codes were uploaded through Arduino IDE.
2- Two water cycles were selected to calculate water loss percentage using the ultrasonic sensor. One at the beginning of each day while one at the end.
3- Over 24 hours, the temperature values were measured and recorded every 1 hour using the temperature sensor and observed through the serial monitor of Arduino IDE. Also, pH readings were measured using the pH sensor every 1 minute, starting with controlled change of pH at 7.5.
4- After the pH of the water was changed, fish was transported into the tank.
5- To achieve the design requirement of sustainability, Estimated Water Pollution Potential (EWPP) value was determined by substituting in Equation (4):

$$\bar{\sigma} = \sum_{i=1}^{n} \frac{\sigma_i}{n}, \qquad \sigma = \frac{30 r_t}{Q} \times S$$

Equation 4: Estimated Water Pollution Potential Equation.

Where $\bar{\sigma}$ is the EWPP. σ is the pollution potential coefficient for a specific polluting substance, r_t is the waste mass of the substance produced during one day of operation, Q is the permissible concentration of the substance multiplied by a volume of 1 m^3, S is a scale factor dependent on the substance toxicity and danger.

3.3: Safety Precautions

Since several electrical components are present in the sandponics system, it is recommended to use a residual-current device (RCD), shown in Figure (38). RCD is a circuit breaker that disconnects the system from the current source if electricity grounds into the water.

Figure 38: Residual-current devices are used to disconnect power from a device in case of danger.

Additionally, wires should never be hung over the fish tank or any wet components. It is strongly recommended that the system is placed on a site away from splashing water and excessive humidity. Furthermore, if extensive connections are made using wires in the prototype, it is essential to organize the wires and keep them neat to avoid tripping hazards.

When dealing with the crops, use gloves whenever applicable and make sure not to dip your hands in the Wet Zone of the grow bed since it can be contaminated with harmful pathogens. You should never work with the system if you have open wounds. The sandponics grow bed and the fish tank could be very heavy. Thus, proper lifting techniques should be applied to avoid backbone and musculoskeletal injuries as well as muscle sprains and strains. Be sure to wear safety boots in case a component falls over.

The sandponics system contains strong acids and bases for controlling pH. Hence, these solutions must be handled with extreme care, and contact with bare skin should be strictly avoided. Moreover, the solutions should be kept in safe and closed storage containers.

3.4: Data Collection

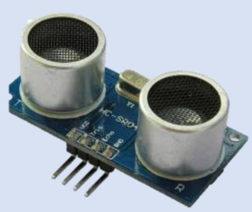
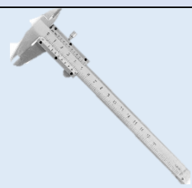
Item	Photo	Usage	Units	Measurement Error
Waterproof temperature sensor (DS18B20)		Measuring fish tank temperature	Celsius Degrees (°C)	± 0.5°C
Gravity: Analog pH sensor		Measure pH of the tank water	______	± 0.1
Ultrasonic Sensor Module for Arduino		Measuring water level to determine water loss	Centimeters (cm)	± 2%
Vernier Caliper		Measure base dimensions to calculate water volume loss	Centimeters (cm)	±0.05mm

Table 2: Instruments and devices used for data collection.

3.5: Results

By following the test plan steps, the following results were obtained, positive and negative.

Negative Results:

The PTC heater was not effective since the aluminum plate covered a relatively small surface area. Thus, due to the high heat capacity of water, the controller took a long time for the heating effects to take place, which was not fast enough to combat fluctuating day-night temperatures.

Positive Results:

The results for the water pH, temperature, and height loss are shown in Figures (39 – 41), respectively.

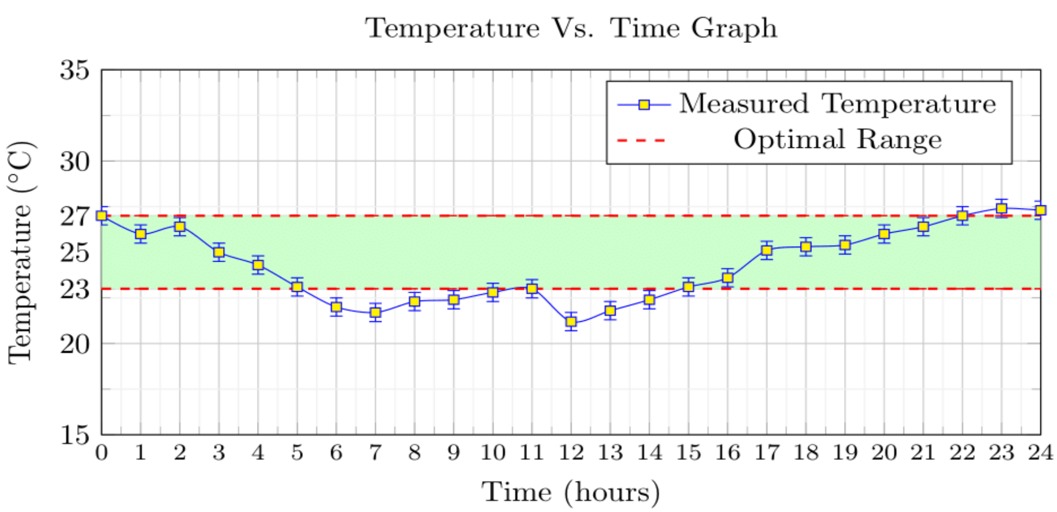


Figure 39: Temperature Vs. Time graph

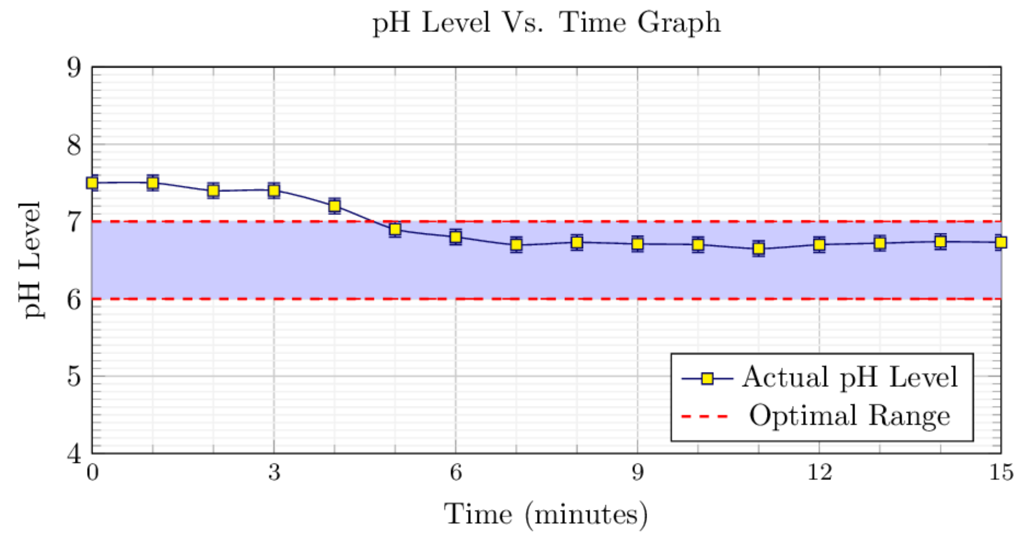


Figure 40: pH Vs. Time graph.

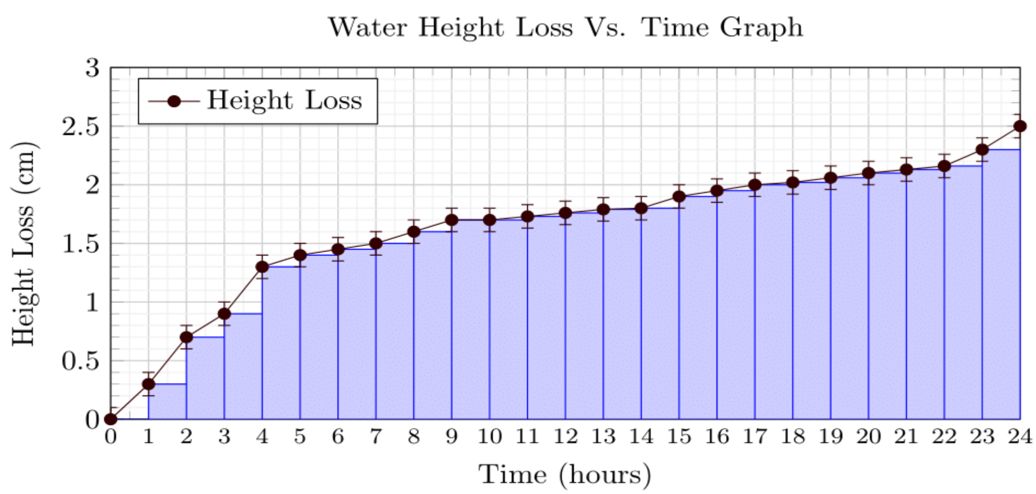


Figure 41: Water Loss Vs. Time graph.

The EWPP value was calculated by substituting σ_i values for the following possible pollutants in an aquaponic system, which are present in high concentrations in fish waste: ammonia (σ_1), phosphorus (σ_2), and iron (σ_3). In Equation (4), the (Q, r_t, S) triplet values for each pollutant were determined based on the available data on water quality standards from WHO and aquaponics calculated performance (Recycling Efficiency ~ 96%) and prior research data. Substituting in Equation (4), the EWPP value is $\frac{\frac{30(2.264\times10^{-3})}{0.25}\times3+\frac{30(2.032\times10^{-3})}{0.1}\times1+\frac{30(1.553\times10^{-4})}{0.3}\times2}{3} = \frac{0.815+0.610+0.031}{3} = 0.485 \pm 0.2$, which is considerably below the design requirement value of 2. Error value was based on different application methods for sandponics and deviation in elements concentration due to diet differences.

Chapter IV: Evaluation, Reflection & Recommendations

4.1: Analysis

Nitrogen Cycle:

The nitrogen cycle in aquaponics, performed in the grow bed, achieves sustainability through filtering the water from the ammonia and making it usable for another cycle, as shown in Figure (42). Different types of nitrifying bacteria turn fish feces, urine and uneaten food, which are diffused in the form of ammonia and ammonium, into nitrates which act as nitrogen sources for the plants. The nitrification process is done through two steps and two different types of nitrifying bacteria: ammonia-oxidizing bacteria, and nitrite – oxidizing bacteria. The ammonia-oxidizing bacteria, Nitrosomonas and Nitrosococcus, change the ammonia in the water to nitrites. These nitrites are then oxidized by the nitrite-oxidizing bacteria, Nitrobacter and Nitrococcus, into nitrates that's an accessible form of nitrogen to the plants. Equations (5.a & 5.b) illustrate these processes.

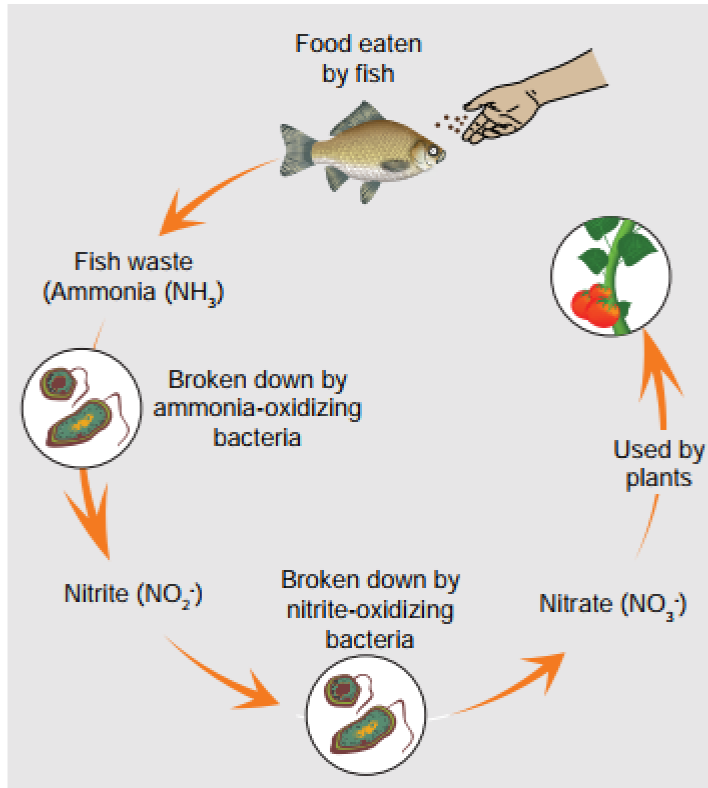


Figure 42: Nitrogen cycle in aquaponics system

$$2NH_3 + 3O_2 \Leftrightarrow 2NO_2^- + 2H_2O + 2H^+ \qquad (5.a)$$

$$2NO_2^- + O_2 \Leftrightarrow 2NO_3^- \qquad (5.b)$$

Equation 5: The nitrification process of nitrogen

Feed-rate ratio:

When concerning the fish feed provided for the fish, it is essential to effectively determine the amount of nutrients supplied since it affects directly both fish and plant growth; when fish is nourished, waste is produced and then converted from harmful ammonia into nitrates usable by plants and makes a cycle shown in

Figure (42). Hence, selecting the proper feed ratio is essential for optimal growth. For green vegetables with plenty of leaves, the feed-rate ratio is calculated based on Equation (6):

$$N_r = A \cdot \frac{45 \pm 5}{Q}$$

Equation 6: Feed-rate ratio equation

Where N_r is the feed-rate ratio in grams of feed per day, A is the plant growth area in square meter, and Q is the effective consumption percentage for fish.

For leafy green plants, like lettuce, one plant takes approximately 0.05 m^2 of area. 3 lettuce heads were planted hoarding an area of 0.15 m^2. Not to mention that since the width of the container equals 30 cm, a free distance of 17 cm is given to each plant, as shown in Figure (43). On the other side, a minimum of 40 g of fish feed is required per square meter, meaning that about 6 g of fish feed are needed for the 3 lettuce heads daily. Further, adult fish often consume about 1 – 2 % of their biomass daily (Somerville, 2015). Hence, a maximum of 300 g of fish biomass is to be grown in the hydroponic part of the prototype. Thus, the automatic feeder is designed so that the servo motor rotates 2 times a day, with each rotation giving out 3 g of fish feed.

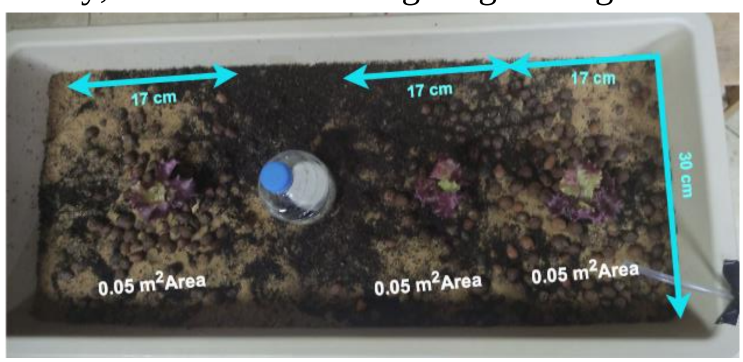


Figure 43: Growing area for lettuce crop

As learned in MA 2.09, it is possible to integrate N_r as a function of time to calculate the required quantity of stored feed for a given time interval, denoted K. Hence, $K = \int_0^t (A \cdot \frac{45 \pm 5}{Q}) dt = At \cdot \frac{45 \pm 5}{Q}$, where t is the time in days.

Water flow dynamics:

As the prototype contains 290 g of fish biomass, a constant water volume of 29 liters is essential to maintain suitable DO levels beside the aeration process. So, better circulation is achieved by cycling the water thrice per hour. For a water volume of 48L in the fish tank, 16L will go into the grow bed within 8 minutes and about 14.2 L return to the fish tank in just 10 minutes while 1.8 liters will remain because of bell siphon mechanism.

As learned in ME 2.05, the concept of power illustrated in Equation (7) can be used to find the power required to pump 16 liters of water with a flow rate of 2 L/min.

$$P = \left(\frac{F_{l/h} \times H_{ft.w.c.}}{9 \cdot 10^5 \times \eta_{Pump} \times \eta_{motor} \times \eta_{VSD}} \right) \times 0.746$$

Equation 7: Formula for required power supply to a water pump.

where P is the delivered power (kW), F is the flow rate (liters/hour), H is the pump head in feet of water column, and η is the efficiency.

Grow bed:

Aquaponics systems have come in three main designs. GMB is the most popular and a relatively inexpensive technique, allowing its application in developing countries. GMBs are based on media for plant growth that satisfy essential criteria, including a sufficient surface area for plant growth, good drainage properties, and neutral pH.

Light Expanded Clay Aggregates (LECA) have excellent performance due to its porosity and large surface area but become quite expensive when used in large amounts. In the project, LECA is used in modest amounts to maintain bacteria growth in biofilter sites inserted in a mixture of sand and river rock, which has the required properties, including availability and wide spacing.

In a grow bed that follows the flood-and-drain circulation method, three zones are created based on their distinguishable water and air content: Dry Zone, Wet-Dry Zone, and Wet Zone. The Dry Zone acts as a shield for micro-organisms from direct sunlight, preventing algal and harmful bacteria growth. Most filtration and biochemical processes occur in the Wet-Dry Zone. Further, red wigglers, which are efficient decomposing worms, are present in this zone. The worms are introduced into the grow beds, where they can break down the organic waste,

Characteristics	*Value*
Organic carbon, %	9.15 to 17.88
Total Nitrogen, %	0.5 to 0.9
Phosphorus, %	0.1 to 0.26
Potassium, %	0.15 to 0.256
Sodium, %	0.0055 to 0.3
Calcium & magnesium (Meq/100 g)	22.67 to 47.6
Copper; mg kg^{-1}	2.0 to 9.5
Iron, mg kg^{-1}	2.0 to 9.3
Zinc, mg kg^{-1}	5.7 to 9.3
Sulphur, mg kg^{-1}	128.0 to 548.0

Table 3: Chemical composition of vermicompost (Garg, Gupta, 2009)

converting them into humus, Nitrogen, Phosphorus, and Potassium (NPK), micronutrients, and growth hormones, as illustrated in Table (3). In addition, the tunnels made by the worms aerate the growing media, providing better conditions for plant growth and bacteria reproduction. Lastly, the Wet Zone represents the mineralization site, which supplies broken-down waste to plants.

To optimize water flow and maximize Wet-Dry Zones, which are essential for growth, a bell siphon is used to apply flood-and-drain irrigation. Bell-siphons let water accumulate in the grow bed up to a specific height, then drain the water into the fish tank. One strength of bell-siphons is the absence of complex technologies as the siphon is composed only of a bell, a standpipe, and a media guard to prevent clogging of bed as shown in Figure (44).

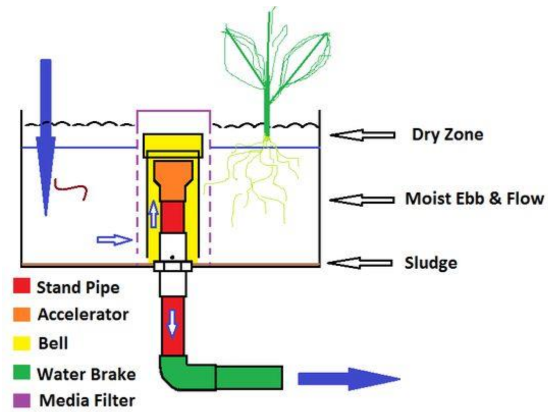


Figure 44: Bell siphon structure and placement in a grow bed.

Pump-based pH controller system:

As studied in CH.2.02, pH is a measure of how acidic or basic a solution is on a scale ranging from 0 to 14 (Zumdahl et al., 2016). It can also be calculated using Equation (8):

$$pH = -\,log\ ([H^+])$$

Equation 8: pH equation for an aqueous solution.

The pH of water is an especially important parameter for lettuce, and the nitrifying bacteria. For plants, the pH controls the availability of micro- and macronutrients in the soil. The ideal pH range for lettuce is 6-7, and a deviation outside this range causes a nutrient lock-out. For the nitrifying bacteria, literature suggests their optimal working pH range to be 7.2-8.1. To conclude, the optimum pH range for aquaponic systems is 6-7. Not to mention that Tilapia fish and the red wiggler worms tolerate pH from 6 to 8.

There are two processes that change the pH in water over time: nitrification process and fish stocking density. During the nitrification process, small amounts of nitric acid are produced as the bacteria liberates hydrogen ions during the conversion of ammonia to nitrate. Additionally, the breathing of fish produces carbon dioxide

(CO_2) that reacts with water forming carbonic acid (H_2CO_3) lowering the overall pH level.

Accordingly, a feedback system, as shown in the flowchart in Figure (45), is initiated for this parameter. A pH meter is used to sense the pH and give value to the Arduino Uno, while the Arduino gives orders, based on the water pH, for two mini water pumps in two tubes. The two tubes contain phosphoric acid (H_3PO_4) and calcium hydroxide (Ca $(OH)_2$). Equations (9.a & 9.b) present the chemical processes that occur during the addition of both the acid and base.

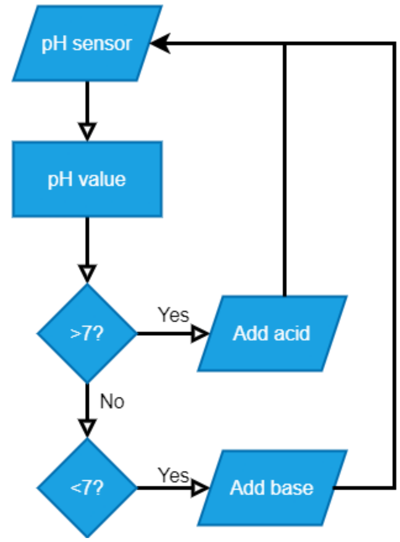


Figure 45: Water pH feedback flowchart

$$H_3PO_4 \rightarrow 3H^+ + (PO_4)^- \qquad (9.a)$$
$$Ca(OH)_2 \rightarrow Ca^{+2} + 2(OH)^- \qquad (9.b)$$

Equation 9: pH neutralization reactions by (a): addition of acid, (b): addition of base

Heating feedback mechanism:

Temperature has a variety of effects on DO level, ammonia toxicity, and biofilter performance. In fact, as the water temperature rises, the solubility of oxygen decreases. Further, an increase in water temperature and pH will lead to an increase in the concentration of toxic NH_3. For example, at a water temperature of 20 °C, 1.24% of the total ammonia is non-ionized at constant pH value. At 25 °C, these values increase to 1.77% (Krastanova et al., 2022). In addition, although Tilapia fish tolerate water temperature ranging between 14 and 36 °C, their ideal temperature is 27-30 °C.

So, temperature is also another water quality parameter that needs to be monitored using a closed feedback mechanism illustrated through Figure (46). The system works by taking a reference input (desired temperature range) and comparing it to the temperature sensor reading. Based on this comparison, a relay module controls switching on and off the heater. If the temperature falls below the desired range, the heater is on; otherwise, the heater is off.

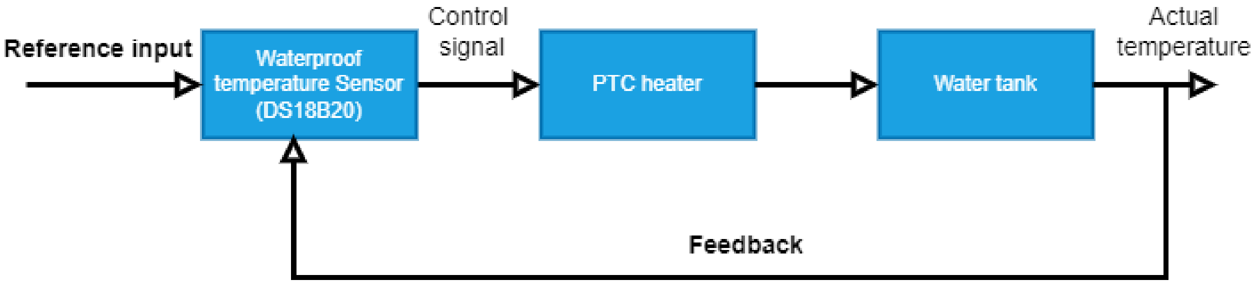


Figure 46: Closed feedback loop for temperature

The aluminum shell PTC heater was selected to be our actuator because of its ability to rapidly increase temperature. PTC heater simply consists of a ceramic thermistor covered with an outer aluminum shell. This thermistor depends on the Positive Temperature Coefficient (PTC) effect. When the electricity passes through the material, its temperature increases. As the temperature of the material rises, its resistance to the flow of electricity increases rapidly, which in turn causes the heat output to increase rapidly as well. This means that the PTC heater can generate a significant amount of heat quickly and efficiently, without wasting energy or overheating. The outer aluminum shell acts as a heatsink that dissipates the heat generated by the thermistor.

As mentioned earlier in negative results, The PTC heater was not able to effectively heat a large amount of water due to its small surface area. So, based on the heat conduction equation that is illustrated in Equation (10), the heat transfer rate of the PTC heater was increased by attaching aluminum fins to increase the surface area in contact with water (Halliday et al., 2020).

$$\frac{Q}{t} = \frac{K \cdot A \cdot \Delta T}{L}$$

Equation 10: Heat conduction equation.

Water loss percentage calculation:

Regarding water loss daily calculation, Ultrasonic sensor is used which emits soundwaves and then receives the reflected waves. So, it can calculate the distance by measuring the travel time and speed of sound from its base to the object. Through the lines of codes written in Arduino IDE, it will calculate the difference between two measurements at the start and end of the day from the water surface. Then, the difference Δh will be inserted through Equation (11) to print the water loss volume percentage:

$$V_L\% = \frac{\Delta h}{h_0} \cdot 100\%$$

Equation 11: Water loss percentage equation.

4.2: Conclusion

The project performance, illustrated in the test plan, provided several compelling results. This study aimed to illustrate enhanced sandponics as a sustainable solution for farming and low-cost nutritional plantations. Subsequently, the continuous recycling cycle of minerals in the prototype provided a productive mechanism to sustain Tilapia and lettuce growth. Further, the application of relatively low-cost control mechanisms enabled the project to operate automatically and maintain near-optimal environmental conditions. The prototype satisfied the design requirements by stabilizing pH and temperature levels as well as maintaining the water level with negligible waste accumulation. Implementation of several modifications, including the bell siphon, helped improve the project performance without the need for advanced technological equipment. Moreover, the project treats issues found in other prior solutions by improving cost-effectiveness and maximizing the usage of waste resources. Subsequently, investing in the project's possible applications represents a potential step toward better access to nutrition and waste management, which further contributes to solving Egypt's grand challenges.

4.3: Recommendations

- Alternative Sources of Protein

Among promising, sustainable, and cost-effective alternatives are the green macroalga Ulva lactuca and the red Pterocladia capillacea. These types of seaweed are widespread along Egypt's Mediterranean coasts. Since they are available all year round and have rich amino acid and fatty acid profiles, they can act effectively as a low-cost protein supplement in fish feed.

Freshwater microalgae have a protein content of 30-50% dry matter and a lipid content of up to 40%. Further, experiments in the Egyptian environment have shown a 50% increase in fish weight and feed conversion ratio compared with traditional crude protein meals (Abd elaziz M, 2015). The price of microalgae reaches 15 EGP/kg, compared with high-quality fish feed, which can have prices exceeding 40 EGP/kg.

- Real-life Application:

A place suitable for aquaponics systems should have essential characteristics, including direct access to sunlight, the availability of a freshwater source in proximity, and climate stability. Subsequently, it is recommended to apply the project in Kafr El-Sheikh governorate, El-Hamool Markaz, shown in Figure (47), because it is a rural area with high population density and has limited access to local nutrition. Further, El-Hamool is close to the Egyptian Mediterranean coasts, which have abundant growth microalgae. This helps decrease transportation costs for fish feed.

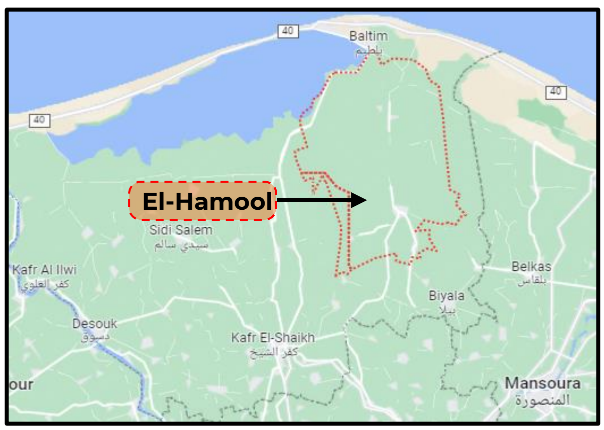


Figure 47: Application of sandponics design in Markaz El-Hamool (red dashes represent El-Hamool borders).

- Intercropping and Vertical Farming

Since supplying large grow beds for plant growth can be expensive, it is essential to be space efficient when using aquaponics. One important method to ensure so is intercropping; since different crops often have varying needs and nutritional requirements, it is recommended to select pairs of crops so that the nutrients left by one crop are utilized by the other. An example is garlic and tomatoes, which combine perennial and annual crops. Intercropping could also be based on other requirements. For instance, a tall crop could be planted with a short crop requiring partial shading. On the other hand, vertical farming by stacking crop layers can handle mass production efficiently.

Different implementation techniques are available, including green hydroponics. Through vertical farming, 1/6 land and 98% less water compared to traditional farming are consumed to produce the same crop quantity. Vertical farming outperforms traditional farming in different aspects as shown in Figure (48).

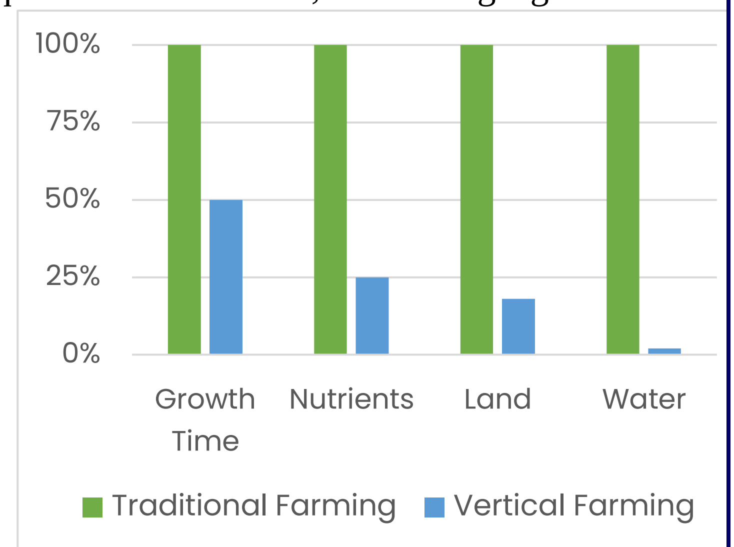


Figure 48: Vertical farming advantages over traditional farming in different aspects.

4.4: Reflections

What would you tell another team who wanted to start where you stopped on your solution?

We suggest that they do more research on possible alternatives for fish feed since it contributes highly to the project operation cost. We also recommend strongly that they take safety precautions when working with the prototype. This includes using gloves for handling pointed rocks and wearing safety boots since some components are heavy and can deal serious damage when falling. Moreover, we suggest that they look for better grow bed media since sand does not provide good conditions for nitrifying bacteria, which decreases decomposition rates and can lead to the accumulation of waste. We advise them to investigate the feasibility of adding an aeration pump to ensure dissolved oxygen does not pose a problem in such a closed environment where oxygen depletion may take place. Finally, we suggest that they use pH controlling acids which have buffering effects to stabilize pH levels as well as compounds which yield beneficial nutrients when dissolving in water.

How did working on this project help you and your team to become better STEM students?

Being involved in this project had a positive impact on us in a variety of ways, whether scientific, engineering, or social.

First, the Capstone project taught us how to apply scientific concepts in real-life applications. We learned that in order to arrive at integrated successful solutions, multiple scientific areas must be merged. Furthermore, the Project work provided us with diverse skills in scientific topics that we could not have obtained easily otherwise.

Second, we learned how to think through the Engineering Design Process (EDP). Applying the EDP allowed us to critically evaluate and process various ideas using a predefined set of methods to arrive at a practical solution for the problem. Thinking using the EDP taught us that it is not essential for solving a problem to arrive at a perfect solution treating all aspects; it is considered good progress if we are able to understand the problem correctly, and even a failed solution helps by offering valuable insight concerning issues with possible solutions. The EDP approach further guarantees that a problem can be addressed efficiently by analyzing and building on the solutions of others.

Finally, the project enhanced our soft skills in a variety of ways. The substantial number of interactions between group members encouraged us to learn cooperation abilities and learn how to do teamwork. We learned how to manage time and effort by adhering to rigid schedules and plans. Finally, the project assisted us in becoming better and more knowledgeable as STEM students.

4.5: Learning Outcomes

Learning Outcome	Description	Concepts	Usage in Capstone
MA.2.07	Given the equation of a function, apply the derivative of that function to solve real-world problems.	- Derivative - Average Rate of Change - Differentiation - Instantaneous Rate of Change	Interpreting feed-rate ratio as the rate of change of a function and maximizing the project efficiency.
MA.2.09	Apply the indefinite integral to model and solve problems	- The Antiderivative Function - Indefinite Integral	Calculate the needed water volume input and the amount of initial resource amount.
MA.2.10	Analyze the distribution of data with a focus on normal distribution	- z-scores - Standard Normal Distribution	Analyze performance and calculate deviation from optimal results.
ME.2.05	Students will be able to apply the concept of power to analyze energy transfer in mechanical systems.	- Power	Analyze the needed input power for the pump to supply desired flow.
ME.2.06.	Students will be able to analyze the movement of a system of discrete masses by using a center of mass approach.	- Attraction of the Earth - Composite Lamina - Toppling - Use of Calculus	Determine the prototype’s center of mass to achieve balance and prevent toppling.
CH.2.08	Students should be able to calculate oxidation numbers of elements in compounds and ions,	- Oxidation Number - Redox Processes - Electron Transfer	Understand the biochemical reactions and effects of positive

	describe and explain redox processes in terms of electron transfer and/or changes in oxidation number (oxidation state…etc.		ammonium ions in the fish tank.
CH.2.10	Students should be able to show awareness of the general lack of reactivity of alkanes, including polar reagents, describe the chemistry of alkanes.	- Empirical, molecular, structural, displayed, and skeletal formulae - Shapes of organic molecules; σ and π bonds - Addition and oxidation reactions	Determine the nutritional content of fish food alternatives and choose appropriate plastic types for construction.
CH.2.12	Discuss how a knowledge of chemistry can be used to overcome environmental problems.	- Environment and Energy	Apply chemistry concepts to reduce carbon footprint and ensure the project is eco-friendly.
CS.2.05	Students identify some concepts about Android operating system.	- Programing languages used to make Android app in Android studio. - Mobile app structure (User Interface, database, programing language, api), JDK, android studio.	Educate the team on making an app to deliver information about project performance.
CS.2.06	Students identify the View objects used specifically for drawing content onto the screen.	- Layouts - Views	Enable the app to display project data effectively.
ENV.2.4.1	Use vocabulary effectively to describe phenomena related to sustainability and pollution.	- Nutrition - Stability - Undernourished - Drainage Nets	Employ precise vocabulary to describe the project processes.

ES.2.09	Students will understand the geologic development of the earth's crust, especially the continental crust of Africa and the Middle East.	- Systems thinking provides a good approach is to apply systems thinking to different stages in the planet's evolution.	Understand geological history of Egypt and rock composition to determine suitable grow bed medium.

Table 4: Transfer of learning in the project through learning outcomes.

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