Journal Of Research Technology & Engineering
www.jrte.org

Sustainable Automated Aquaponic Systems for Highly Urbanized areas in Sri Lanka

[1]Ishari Dilmini, [2*]Aravinda Jayakody, [1] D.D.P. Preethika

[1]Faculty of Technology, University of Sri Jayewardenepura
[2]Faculty of Applied Science, University of Sri Jayewardenepura

*aravindajayakody96@gmail.com

Received:15 June 2021; Revised: 26 June 2021; Accepted:28 June 2021; Available online: 10 July 2021

Abstract: Agriculture is currently a significant contributor to the Sri Lankan economy, but there is still a lack of integration of modern technology with agriculture. Over the past few decades, many people are moving away from agricultural occupations due to urbanization. As a result, the higher portion of the food items in the urban areas has to be transported from distant agrarian lands. This has led to creating several issues such as food getting damage by transportation, quality reduction, and the increment of food wastage. As a consequence, customers are experiencing high food prices. Moreover, using water for agriculture has become a widely concerning matter worldwide, especially in urbanized areas. To overcome the emerged problems, Aquaponic systems for urban cultivation can be introduced. Aquaponics is an innovative and sustainable production system and plays a critical role in the environmental and socio-economic sustainability of the agricultural sector. Aquaponics system can be producing healthy local, fresh food products with a short supply chain in terms of a pesticide-free environment. This will be the best solution for highly urbanized areas, and it is already successful in many parts of the world. Therefore, this article mainly focuses on introducing an eco-friendly aquaponic system design for highly urbanized areas in Sri Lanka.

Keywords: aquaculture, aquaponic design, fish, hydroponics, plants, sustainable, urban aquaponics.

1 INTRODUCTION

As the population grows over 7 billion [1], the world continues to run out of space. People try to build high rises buildings, and parallelly, vegetation and farming space are steadily thinning, and humans are forced to develop solutions to sustain the legacy of farming [2]. Food consumption has also increased in proportion to the growing population. So food has become a consumptive substance immediately. Therefore, it is essential to have a sustainable system. This is where Aquaponic systems have become the most suited technology to tackle urban agricultural limitations. Aquaponic systems primarily target people who lived in apartments or in houses with insufficient space for agricultural activities [3].

The Aquaponics term is derived from the concept of aquaculture and hydroponic. Aquaculture can be identified as raising aquatic species (fish, molluscs, aquatic plants, algae, and more) under a specific control mechanism. Besides, hydroponic is a widely applicable common method in soilless culture, and this can be identified as a method of growing agro plants without any soil medium. Here, instead of soil medium, various substrates can be used as the supportive method for plant growth. Thus, aquaponics is a combination of applying both these concepts into one integrated system [4].

The basic process behind aquaponics is that recirculating aquaculture products into the hydroponic system. Here, aquaculture fish waste provides an organic food source for the plant's growth in the hydroponic systems, and the plants naturally filter the water for the fish [5]. So, fish and plants contribute as the primary participants to effectively operate the system. Besides that, microbes (especially nitrifying bacteria) act as the third participants for the system operation. These bacteria convert ammonia from fish waste into different forms of nutrients. Plants in the hydroponic system can uptake these nutrients and use them for their growth. Besides, solid fish waste is also turned into vermicompost, which also acts as plant growth material [6].

Moreover, Aquaponics capitalizes benefits and ultimately eliminating the drawbacks of both hydroponic and aquaculture systems. There are multiple benefits related to the aquaponic systems, such as less space, fewer maintenance requirements, and minimum inspection to operate. Moreover, the aquaponic systems run on the automation concept, which can be further utilized for small-scale/ domestic and fresh commercial food production. Therefore, this research mainly focuses on finding out the suitability of aquaponic systems and introducing a new system for domestic usage in Sri Lanka. Here, it has been investigated the basic principles of aquaponic systems, common drawbacks and further gives some points of view to overcome the existing limitations by promoting new design.

2 Aquaponic System Operation

The basic principles under aquaponics are that the waste from one biological system can be used as a resource for another biological system. Therefore the fish and plant culture can be combined to produce several products at once, and water can be reused through biological filtration and recycling processes. These systems mainly encourage the local food production process, and it provides access to healthy food and improves the local economy [7].

The process is mainly started with the fish waste effluent, and this nutrient-rich effluent from fish tanks is used to fertigate the hydroponic production beds in the aquaponics system. Here, waste material (fish excreta, waste residuals) containing ammonia particles will be released into the tank, and nitrifying bacteria (ammonia-oxidizing bacteria) start to convert ammonia into nitrite. Furthermore, nitrite-oxidizing bacteria begin to convert nitrite into nitrate for plants [8]. This process is called the nitrification process and ultimately provides nutrients for the plant's growth. Similarly, this causes to eliminates ammonia and nitrite, which can be toxic for system conditions.

Nevertheless, hydroponic beds act as a biological filter by removing ammonia, nitrate, nitrite, and phosphorus. Therefore, purified water can be reused again for the fish population[8]. Similarly, the nitrifying bacteria where live in the gravels (along with the plant roots) play a crucial role in nutrient cycling because the system will inactivate without them. So, this primary biofiltration process or nitrification process is illustrated in Fig. 1.

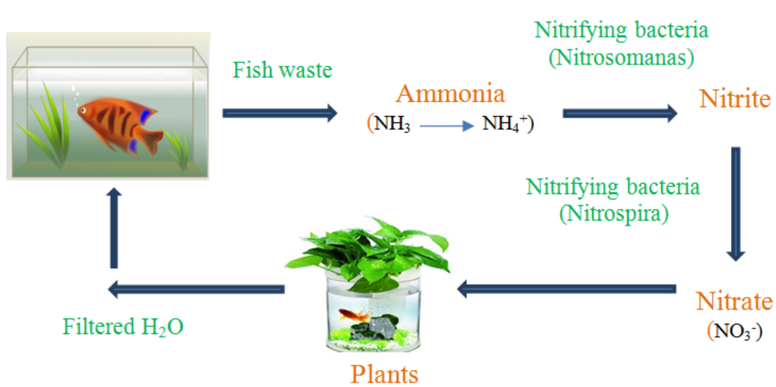

Fig.1. Schematic representation of aquaponic biofiltration process

3 Drawbacks of existing systems and suggested modifications

Plants, fish, water can be considered the main elements of the aquaponic system, and each of these was having specific problems in terms of its operation [9]. Therefore, concerning all these aspects are much essential for successful system operation.

3.1 Plants

The plants' growth rate may be reduced, and even plants' leave color might be changed due to the lack of nutrition [10]. So, balancing the aquaponic ecosystem is the recommended solution to overcome these consequences because there are practically determined ratios for plants and fish stock. Also, plants can affect various deficiencies and toxicity conditions because of some nutrients [11]. Therefore, farmers should encourage to grow plants that can survive in different nutrition prosses, which may occur with the fish waste. However, the plant should have enough resistance against some pathogens. Sometimes the leaves of plants can turn yellow despite the high nitrate level because of many reasons. It can be because of the exposure to less sunlight or may due to the variant nutrient deficiencies [10]. It can be recommended to check the quality of the water, nutrient concentration, the amount of sunlight level periodically and adjust them to the desired level. In such a context, selecting locally available plant species and accurate system conditions can ensure healthy plant growth.

3.2 Fish

Fish feed is an essential requirement for their growth, especially for the nutritional process. It should have a correct balance of protein, carbohydrates, fats, vitamins, and minerals. Therefore, special attention should be given to homemade fish feeds for better operation [10]. Sometimes, fish refuse their food, and mostly this is occurring due to the inappropriate water quality.

The water temperature also can affect the fish's rise because fishes have less ability to adjust variant temperature ranges. But, in Sri Lanka as a tropical environment condition, and it can be evaded easily. Also, properly acclimatizing fish to the new water is a more critical process because adapting fish to new tanks can be a very stressful process for the fish, particularly people who practice transporting fish via polythene bags or using small tanks [12]. In such a scenario, temperature and pH changes in original water and new water become the most dominant factors that cause stress when acclimatizing fish. It was estimated that if the pH difference between the culture water and transfer water values is more than 0.5, then fish need at least 24 hours to adjust to the new environment. This problem can be minimized by floating sealed transport bags containing fish in cultured water, allowing to equilibrate the temperature slowly [13].

However, the optimal balance of fish biomass and the biofilter size is the most important factor to adequately convert ammonia into nitrite. Moreover, excess fish and plants can result in insufficient nutrients concentrations to cover the plant's demand. Therefore, it is recommended to adjust the correct ratios of fish and the size of the biofilter.

3.3 Water

Water is the most dominant medium by which fish received the oxygen and nutrients transport to the plants. The pH change of the existing water is one of the critical problems in aquaponics. This may cause because the high ammonia concentration in existing water. Therefore the filter can use natural pebbles and shells, and then the pH can be maintained with the desired level. Increased nitrate and nitrite levels are also an issue when considering water quality. So it can be minimized by adding charcoal or aquatic plants like water hyacinth to the fish tank [10].

The growth of algae can also be a problem in the aquaponic system [9]. Often it can be caused by sunlight. Thus, it can be recommended to add shrimps or algae-eating fishes to overcome the issue. Dissolved oxygen, pH, temperature, total nitrogen, and water alkalinity are the most dominant water quality parameters in aquaponic systems. Each of these parameters having its impact on the fish, plants, and bacteria in the system. Therefore, it is crucial to have adequate knowledge and periodical water testing methodology to determine the changes of each parameter. For example, the low dissolved oxygen concentration is affected for both plants and fish, which can be minimized using aeration pumps. Because good water circulation in the aquaponic system ultimately enhancing the high concentration of dissolved oxygen [10]. Furthermore, experimentally identified fish species that can survive in different environments will be the most vital solution for many issues in both water and fish.

Concerning all these aspects, it is essential to identify proper requirements for the proposed system design.

4 REQUIREMENT ANALYSIS OF PROPOSED SYSTEM

Plants and fishes selection for the aquaponic system is the most crucial aspect of the aquaponic system setup. Fishes and plants are the primary and living creatures of the system. The size, weather conditions in the selected location, and the system's expectations are the most dominant factors that need to be considered for plant and fish selection. Typically, urban aquaponics system size can be limited to several square feet. Those types of systems can implement 63 - 108 square feet in an open space [14]. Plants and fish need to match with the tropical environment. Sri Lanka is a tropical and quite hot country, so the weather has not changed very much over the year [15]. Thus Sri Lanka is the more suitable place to establish aquaponics systems.

4.1 Fish selection

There are multiple types of fish that can adapt well to being raised in an aquaponic system. Aquaponics fish should be chosen based on their disease resistance, the ease of raising them, and growth time [7]. Multiple fish species had already been recorded by showing excellent growth rates in aquaponic units, including '*Tilapia, Trout, Common carp, Pacu, Silver carp, Grass carp, Barramundi, Jade perch, Catfish, Arctic char, Salmon, Murray cod, and Bass.'* They can survive in different temperature conditions [8].

Among them, Tilapia is the most common species that can be seen in commercial aquaponics systems. Since they are edible fishes and most countries, tend to produce fishes from their home tanks to add to their diet [16]. Since most Sri Lankans do not tend to kill fish on their home tanks, they can farm fish as pets or as a vendible production in Sri Lanka urban aquaponics.

Besides that, enough awareness and knowledge regarding fish farming is a key requirement for successful operation. Moreover, *Catfish* and the *Gourami* species can also be considered the most suitable species for aquaponics systems in Sri Lanka. They have a great survival rate with variant temperature, oxygen, dissolved solids, and pH changes [17]. Therefore, both these species can be proposed for our system design. The important point is that the *Gourami* species are herbivores and the *Catfish* species are carnivores, but for survival, *Catfish*shows omnivore's behaviors [18]. So, it is not mandatory to have a wide range of knowledge on aquaponics to maintain both these species. Table.1 shows the comparison of the required operating conditions for both fishes [19] [20].

Table 1. Optimal water qualities for catfish and gourami

Type of conditions	*Catfish*	*Gourami*
Temperature	80 - 85 °F	73 - 84 °F
pH	6 – 9	6.8 - 8
Salinity	500 - 3000 ppm	--
Dissolved oxygen	5 - 15 ppm	> 2 ppm
Nitrite	0 ppm	<0.5 ppm
Hardness (CaCO3)	20 - 400 ppm	50 - 100 ppm
Ammonia	<0.2 ppm	< 1 ppm

4.2 Plant selection

The selection of plant species for hydroponic culture (in the aquaponic system) is related to fish stock density and nutrient concentration after aquatic wastewater. In general, fast-growing plants with a low nutrient demand are well adapted to the aquaponics systems in the first few seasons [8]. After two to three seasons, the system will be well-established, and it is ready to yield fruiting vegetables that higher nutritional demand [7].

Typically, greenhouse plants (*swiss chard, pak choi, Chinese cabbage, collard, watercress, Lettuce, tomatoes, cucumbers, eggplant, okra*) and herbs (*basil, cilantro, chives, parsley, portulaca, and mint)* are planted on an aquaponic system [21]. For Sri Lankan urban aquaponics, we can apply vegetables like bell peppers, tomatoes, chilies, cabbage, and fruits like strawberries and watermelon, etc. Those are mainly suitable substitutes for daily usage and trusted organic consumption with some economic feasibility. Apart from that, culinary herbs such as *Basil, Parsley,* and *Mint* can also be identified as adaptive crops for Sri Lankan urban aquaponic [16]. Since they are costly, it gives much economic value with small amounts of production.

5 PROPOSED SYSTEM DESIGN

The main function of an aquaponics system is to circulate water between plants and fish tanks. The system has 3 functional parts for processing as a fish tank, cultivation trays, and filter. The proposed system's main features and measurements are mentioned below Table. 2.

Table 2. Components of the Proposed system

Features/ Functional parts	Description with measurements
Fish tank	• $5 \times 2 \times 2$ ft^3 PVC tank can be used as the fish tank and it should be filled with water up to 1.5 ft.
Growing beds	• This is used for crop cultivation and can be designed using 4×4 in^2 square-shaped PVC pipes. Nine PVC pipes can be recommended. • Clay balls are used as the filling material for growing beds.
Filter	• 1ft diameter and 2ft height of barrel can be recommended for the filter. • The barrel is divided into two parts, a submersible water pump (having 1800 L/h of flow rate) can be mounted at the left corner of the barrel and a separate filter system can be used for other corners.

The schematic design model for the proposed aquaponics system with the components is shown in Fig.2.

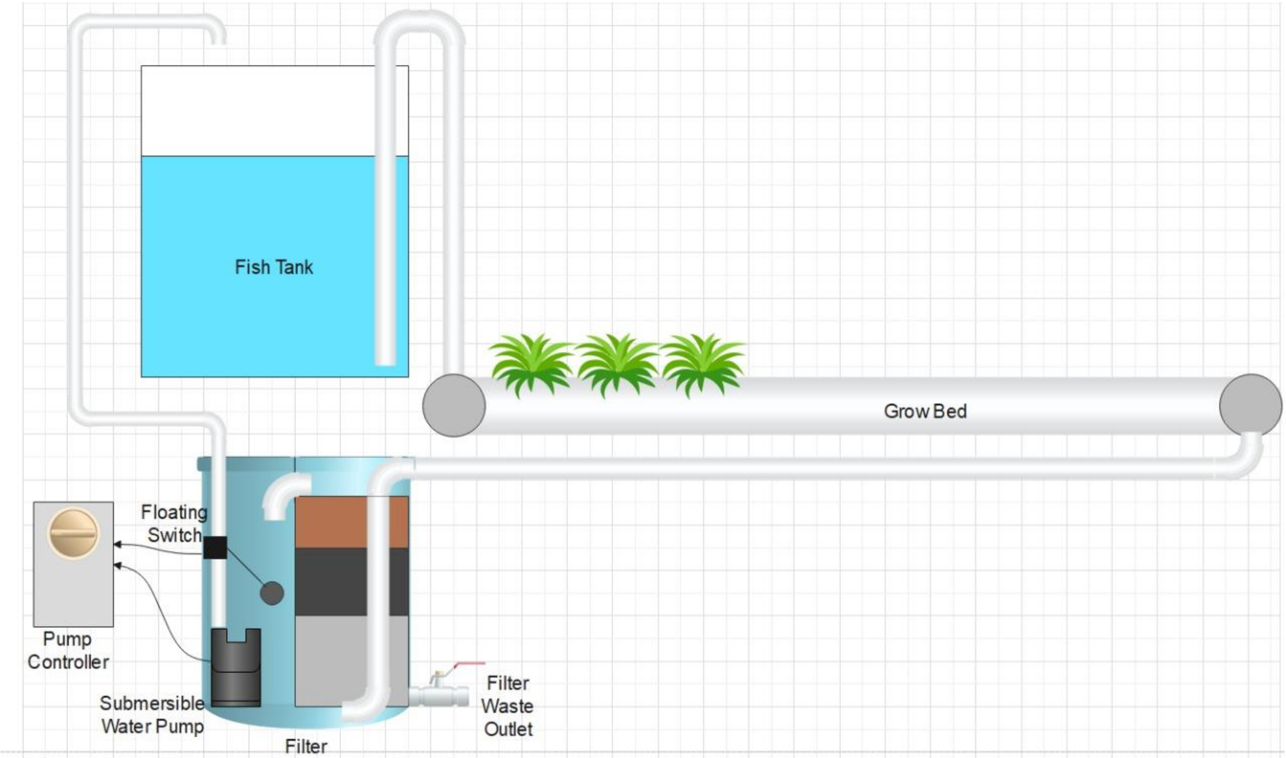

Fig.1. Main components of the proposed Aquaponic system design

The standard ratio between growing beds and fish tank volume is 1: 1 [22]. But there are times when this ratio changes to 1: 3 [23]. Therefore, in this design, it is recommended to change the ratio from 1: 1 to 1: 2; it is more effective to change the length of the PVC pipes in the growing bed trays from 20 feet to 10 feet.

The growing bed acts as a biological filter, and the clay balls in the ever-increasing bed provide a surface for Nitrosomonas and Nitrobacter bacteria to inhabit. Growing beds have a dark environment that promotes bacterial activity and leaves enough space for plant growth. Compare with the other substrates; clay balls perform effective results because of their lightweight.

Here, the separate filter system can be mounted at the right corner of the filter tank, which is supposed to be connected with the growing bed effluent pipeline. This can be used for the further increment of purification process efficiency. This is proposed to be prepared by using 3 layers, including the rocks and shells layer (at ground level), coconut shell charcoal layer (second layer), coir net (top layer), respectively. The ground-level layers can be used to reduce the acidity of the water and act as another biological filter. The second layer can be used to remove toxins from the water, while the top layer can be used to avoid the movement of solid waste to other units/ components in the aquaponic system. Then, filter waste can be easily removed through the drain tap at the bottom. Fig.3 illustrates the plan view of the whole proposed aquaponics system with nine growing beds.

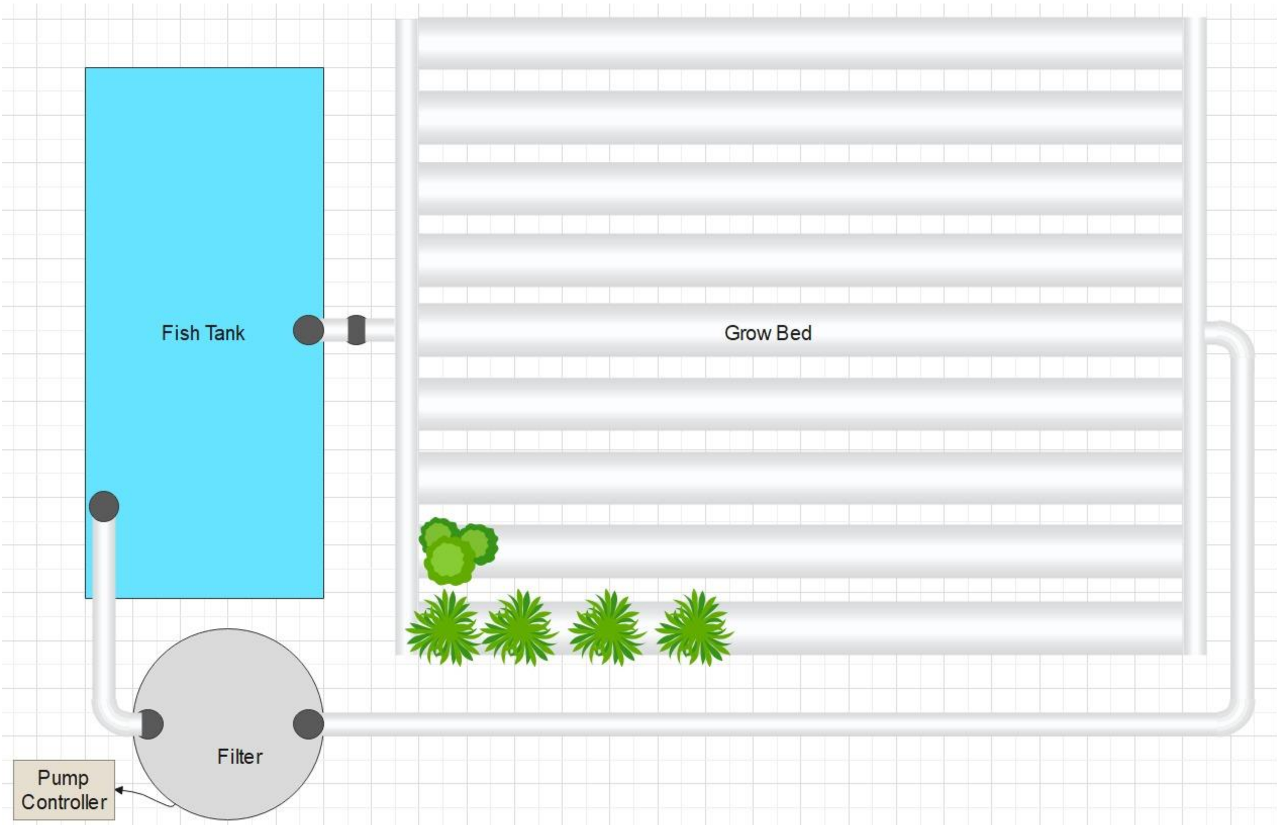

Fig.2. Plan view of the Aquaponics system

One of the significant drawbacks of aquaponics is high energy for water circulation [10]. However, the water is often flowing under gravity pressure from this proposed system, and a timer and a floating switch control the water pump. The timer can give a specific period to operate the filter throughout the day (typically 10 hours or 15 hours). At the same time, the floating switch activates the water pump following the water level in the filter. So, even though there is no water in the filters, the system will automatically stop. Thus, it is an adequate energy (electricity) saving method, and it avoids motor damage in such incidents. Other than that, there are air pumps to aerate the system for the conventional aquaponics system. Still, here we proposed increasing the height of the filtered water carrying line to enhance the natural aeration efficiency. Thus, it does not require an additional power source to aerate the water in the fish tank. We recommend that it is enough to supply sufficient O2for the selected fish stock. As we recommend this system for the outdoor environment (especially for balconies, slabs, open spaces, etc.), it is unnecessary to apply growing light.

Consequently, outdoor aquaponic primarily increase the water evaporating rates from the system. Therefore, it is recommended to mounting a shade net on the top of the system. This will reduce water evaporating rates, protect plants from excess sunlight, and further protect the fish tank from predators.

6 CURRENT STATE AND FUTURE PERSPECTIVES FOR URBAN AQUAPONICS

The present study with the proposed system design shows that aquaponics is a more suitable concept for the urban areas of Sri Lanka. However, this would be a good option even for rural areas to get fresh, fully organic food production with assurance. So it supplies two agricultural products (fish and plant) using one nitrogen source.

The proposed system combines both fish and plant cultivation by recirculating the ecosystem inside the system. The system consists of a low waste generation concept, and all fish wastes are recycling back to the system. So, natural nitrifying bacteria play a critical role by converting waste into plants' nutrients. Thus, it's unnecessary to add additional water, chemicals, or fertilizer for plant growth. So this has the potential to reduce agricultural water consumption by up to 90%. Therefore it can recommend these systems for the people who do not have sufficient water for their agricultural works or either people who pay for water. But, in the future, we can develop this concept for the dry zone areas as a commercial/ domestic agriculture system.

Apart from that, lack of soil availability and lack of space for agriculture are some emerging problems in highly urbanized areas. Therefore, people need to encourage to grow plants without any soil medium using the proposed design. Alternatively, clay pebbles can only be used as structural support and can be reused multiple times with more plants. Furthermore, providing good mental health is another advantage of urban aquaponics.

When it comes to the vulnerability of that system, the initial implementing cost can be pretty high. But that whole system can be used for more than 5 years; thus, it reduces vulnerability.

7 CONCLUSION

Aquaponics is a modern and sustainable agricultural concept that relies on primitive energy and material inputs rather than traditional production methods. Also, aquaponic systems adapt well to the principles of the circular economy with their circular process and minimize the impact of the agro-food sector on the environment. This aquaponics system is well adapted to the existing social and economic systems of Sri Lanka and has the potential to be used sustainably for urban cultivation. This simple design can be used as a basis for that. This can be started as a pilot project to educate the public about aquaponics. This could later be developed as a productive, innovative farming industry than the current economically and technologically enhanced agricultural lands. Therefore, utilizing this alternative method can secure the Sri Lankan agriculture and food sector. In such an initiative, we need to be on the right track with this novel farming method to create sustainable nature.

REFERENCES

[1] Max R., H. R. (2019, May). Retrieved May 6, 2021, from Our world in data: https://ourworldindata.org/world-population-growth

[2] Olivier, A. (2018, November 14). Retrieved May 6, 2021, from Agrilinks: https://ourworldindata.org/world-population-growth

[3] Andreas Graber, N. A. The multifunctional aquaponic system at ZHAW used as research and training lab. Conference VIVUS – on Agriculture, Environmentalism, Horticulture and Floristics, Food Production and Processing and Nutrition. Slovenia, 2014.

[4] Adler P.R., Harper, J.K., Wade E.M., Takeda F., Summerfelt S.T. Economic analysis of an aquaponic system for the inegrated production of rainbow trout and plants. International Journal of Recirculating Aquaculture, 1 (1), 15-34, 2000.

[5] Alexandratos, Nikos & Bruinsma, Jelle, 2012. "World agriculture towards 2030/2050: the 2012 revision," ESA Working Papers 288998, Food and Agriculture Organization of the United Nations, Agricultural Development Economics Division (ESA).

[6] Bittsanszky, A., Uzinger, N., Gyulai, G., Mathis, A., Junge, R., Villarroel, M., Kotzen, B., & Komives, T. Nutrient supply of plants in aquaponic systems. Ecocycles, 2(2), 17–20, 2016.

[7] Diver, S. (2006). A Publication of ATTRA - National Sustainable Agriculture Information Service. Retrieved 11-06-2021, from Aquaponics - intragration of hydroponics with aquaculture: www.attra.ncat.org

[8] Kamal G., Santa C. Rview of Acuaponics system: Searching for a technically feasible and economically profitable aquaponics systems. Journal of agricultural environmental and consumer sciences, 19, 5- 13, 2019.

[9] Natalija A, Vanja. S. Analysis of application of aquaponic system as a model of the circular economy - A review . Recycling and sustainable development, 13, 73-86, 2020.

[10] Somerville C, C. M. (2014). Small-scale aquaponic food production. Food and Agriculture Organization of the United Nation. Rome. http://www.fao.org/in- action/globefish/publications/details-publication/en/c/338354/
[11] Rakocy J.E., Michael, P.M, Thomas M.L., Marley B. (2006). Recirculating aquaculture tank production systems: Aquaponics intergrating fish and plant culture . Southern region aquaculture center. https://extension.okstate.edu/fact-sheets/recirculating-aquaculture-tank-production-systems- aquaponics-integrating-fish-and-plant-culture.html [Accessed on: 22/06/2021].
[12] Tyson R.V, Eric. H.S., Danielle D. T , James M. W, Amarat S. Reconcilling pH for Ammonia Biofiltration and cucumber yeild in a recirculating aquaponic system with perlitrn biofilters. American society for horticultural science. 43 (3), 719-724, 2018.
[13] FAO . (2015). Management of the aquaponic systems. Food and Agriculture organization of the united nation.
[14] Christopher S, M. C. (2014). Small scale aquaponic food production - integrated fish and plaant farming. Rome: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
[15] Department of Meteorology - Sri Lanka: https://www.meteo.gov.lk/index.php?option=com_content&lang=en [Accessed on: 11/06/2021].
[16] James E. R., Michael P. M, Thomas M. L. Recirculating aquaculture tank production systems: Aquaponics - Integrating fish and plant culture. Agrilife Extention. COLLEGE OF AGRICULTURE, FOOD AND ENVIRONMENT, 2006.
[17] Sumbodo B T, Financial feasibility analysis of Gourami Farmming in a collaborated business assocation system. IOP conference series: earth and environmental science. IOP publishing, 2021.
[18] Chandler, L. (2019, April 16). Hooked on catfish. Retrieved June 11, 2021, from Are Catfish Carnivores, Omnivores or Herbivores?: https://www.hookedoncatfish.com/
[19] Ceraig S T, E. H. (1990). Channel catfish farming hand book. International Thomson Publishing.
[20] Cheristopher, B. (1999). A manual for ccommercial production of the Gourami, Trichogaster, Trichopterus, a temporary paired spawner.
[21] Savidov NA, Fish and plant production in a recirculating aquaponic system: a new approch to sustainable agriculture in Canada. International conference and exhibition on soiless culture, 2005.
[22] The aquaponic source. (2020). Retrieved June 15, 2021, from https://www.theaquaponicsource.com/
[23] Yousef S, Aftab A, Mohamed S.B. Food production and water conservation in a recirculating aquaponic system in Saudi Arabia at different ratios of fish feed to plants. Journal of the world aquaculture society, 39 (4), 510-520, 2008.