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The Design and Development of Aquaponics Piping System for Urban Farming

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Abstract: Aquaponics is a recirculation system that combines aquaculture units and hydroponics units in one system to facilitate consumers living in urban areas to get a supply of fresh and nutritious vegetables and fish protein. The Aquaponics system that was developed is using the Nutrient-Film Technique (NFT). To fabricate this system, three designs concept were compared and selects designs that are capable of maximizing production and affordable development costs. The objective of this project is to design and fabricate an aquaponic system and test its level of effectiveness on water, energy, and nutrients. After finalizing the design, the preparation of equipment such as water tanks, biofilters, hydroponic units made of PVC pipes, and pumps. As a result, the selection of the finalized design used to fabricate this system is able to operate well because, a comparison between the three models has been made based on Morphology Analysis that consist of four elements that have been evaluated namely the elements of manpower, machine, material, and money. The duration taken for this fabrication completed in 3 weeks. After completing the fabrication process, fish and plants were added. The levels of ammonia, nitrite and pH values was collected for fish tank 1 and fish tank 2. The flowrate of water was good and the calculation also has recorded. This shows, the biofilter used is suitable and effective. Therefore, design drawings be created in more than two concepts before a project is developed, so that analysis may be performed to save costs and increase product production while also increasing efficacy.

Keywords: Aquaponics Nutrient Film Technique, Design Selection, Fish Selection Lettuce, Spinach And Basil, Ammonia, Nitrite

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1. Introduction

Due to rapid urbanization, land resources for agriculture have been decreasing. The fast expansion of the human population has led to an increase in the pressure placed on the world's food supply. However, the conventional techniques for cultivating plants need a substantial amount of space, as well as time and labor. Because of this, there is an increasing concern for food supplies that are both safe and sustainable, which has resulted in the need for the development of innovative farming methods [1]. Because it is largely urbanized and has limited area for conventional agriculture. So, aquaponics could be a good solution for food security and sustainability. Developing an aquaponics system is not an easy thing and it is quite hard. Therefore, the piping system is playing a major role in developing the aquaponics system. To make the system work properly, each component must act in coordination. Plumbing, also known as pipework, is an important part of aquaponics. Without it, water and nutrient circulation would be impossible, and plants and fish would die. When planning an aquaponics system, consider the pipes from the beginning. However, with so many alternatives, selecting the ideal pipe sizes for aquaponics systems might be more difficult than it appears.

Aquaponics is a term that refers to the practice of combining aquaculture with hydroponics. Aquaponics is a method of growing fish and plants together in a closed system that eliminates the need for soil. Excess fish waste provides nutrients to the plant, while the plants themselves operate as a natural water filter for their habitat. The fish and vegetables that are grown via the use of aquaponics are not only organic but also fresh. When combined with a greenhouse that maintains a certain environment, aquaponics makes it possible to grow high-quality vegetables all throughout the United States over a period of several months [2]. Aquaponics combines the benefits of both systems while eliminating the drawbacks of each. Aquaponics employs extremely nutritious fish effluent, which includes virtually all of the nutrients necessary for maximum development, rather than hazardous chemical solutions, to produce plants. In aquaponics, the water is cleaned and purified by the use of the plants and the medium in which they grow, and is then circulate back through the aquarium to the fish [3].As a result of its role as a Bio-Filter, in which it gathers and processes the waste and ammonia produced by the fish, it is able to restore fresh feed water. In addition, by growing plants in the filter system, we used up the nutrients and nitrates produced in the filter system, producing excellent quality fresh vegetables for our tables. It's ideal for our needs [4].

The aim of this study is to design and make comparisons in the selection of aquaponics system. We will design 3 concepts in solidwork and then finalized one. After that, to develop a Nutrient Film Technique based Aquaponics System for urban farming that can growing up the aquatic species and soilless plants in a single recirculating system. Finally, to test the aquaponics system in terms of water, energy and nutrient.

2. Literature review

Fish waste is turned into dissolved nutrients like nitrogen and phosphorus by bacteria in the aquaculture portion of the system, which are then utilized by plants in a hydroponic unit to flourish. Through the reduction of effluent volume as well as fish habitat quality improvement due to nutrient removal, the use of water as a whole is also reduced [5]. Water, oxygen, and nutrients must be measured and calculated to ensure that the plants are receiving an adequate supply of these elements [6] The length, channel slope, and rate of flow must be estimated to ensure that the plants have adequate water to flourish. it can produce a lot of plants. In NFT systems, the bio-filter is critical since there is no large space for helpful bacteria to grow [7]. The Tilapia farm made use of a 100-gallon stock tank manufactured by Rubbermaid because of its capacity to store a significant amount of food and because it was used as a fish tank [8] Every fish tank needs to have a lid on it. An external biofilter should be installed so that nitrifying bacteria may colonise and convert fish waste's toxic ammonia into nitrate, which plants can easily assimilate [9]. As a mechanical particle filter, the gravel on the bottom of the tank collects and blocks solid faeces matter deposited by fish from entering the layer [10]. According to the results of ammonia and nitrite measurements taken daily, the biological filter was working as expected, as ammonia was oxidised into nitrate. Biofilter bacterial biomass may be maintained at constant state, reducing the net nutrient absorption that bacteria were originally responsible for during the hydroponic studies [11] In general, lettuce, herbs, and speciality greens (such as spinach, chives, basil, and watercress) have low to medium nutritional needs and are well matched to the aquaponics system since they grow quickly and Tilapia, trout, perch, Arctic char, and bass are among the warm-water and cold-water species that are best suited to recirculating aquaculture systems [12]. Common and safe to use are PVC and CPVC. HDPE pipe is an alternative for pipes, although it has fewer choices in fittings and is more difficult to locate [13]. Seals such as Uniseals and Bulkhead Fittings must be developed to meet the needs of the industry. PVC pipes are available in a variety of lengths and diameters. [14]. Most aquaponics systems should have dissolved oxygen concentrations of at least 5 ppm. Warm-water fish such as goldfish, tilapia, bass, and catfish prefer temperatures ranging from 65° to 85°F, whereas cold-water fish such as trout thrive in temperatures ranging from 55° to 65°F [15]. An acidic environment is indicated by the pH scale's zero-to-seven range, seven indicates a neutral environment, and seven to 14 indicates a basic or alkaline environment [16].

3. Methodology

3.1 List of material

The materials are used to develop the aquaponics piping system. This research was conducted as part of comprehensive evaluation on the literature of aquaponic system preparation.

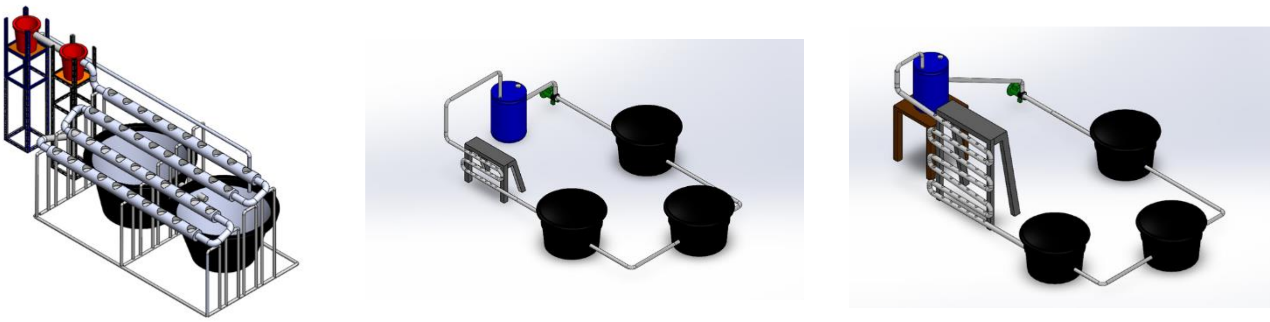
Table 1: List of material

Material	Diagram
Polyethylene Tank	
25L Bucket	
0.75 hp sump pump	
90° Elbow	
PVC pipe	

Tee	
K1 biofilter	
Boltless rack	

3.2 Morphology Design Selection

Morphologies are the term used to describe the solutions obtained by this method. As a result, the designer has developed a practice of swiftly settling on one design option, which is then constantly refined until a good one is determined throughout the design development process. Future manufacturing operations will be greatly affected by the choices made during product design and development. All solutions, technologies, or systems that meet the design's overall and specific performance objectives should be investigated by the designer. The process of choosing the optimal aquaponics system design for my project began at this phase. Essentially, all three models are based on the same hydroponic system, but in various locations and techniques. Human, material and financial resources are the four key components of the project we're working on. Considered a successful way of finding answers, this strategy uses multiple comparable sources to look at a larger variety of design options and see what works best. The Figure 1 (a), (b) and (c) shows the illustration of proposed concept design of aquaponics piping system.



(a) Concept 1 (b) Concept 2 (c) Concept 3

Table 2: Comparison in Design Selection

Elements	Concept 1	Concept 2	Concept 3
Manpower	One manpower	One manpower	One manpower
Machine	0.75 HP sump pump	1HP centrifugal pump	1HP centrifugal pump
Materials	• 150-gallon polyethylene tank • 75-gallon polyethylene tank • 25L drum tank • PVC pipe 2” • PVC pipe 3” • 90° Elbow 2“ • Tee 1.5 inch” • PVC pipe 1.5inch • K1 biofilter • Net pot hydroponics • Boltless rack	• 100-gallon polyethylene tank • 150L drum tank • PVC pipe 2” • PVC pipe 3” • 90° Elbow 2“ • Seashell and gravels • Net pot hydroponics	• 100-gallon polyethylene tank • 150L drum tank • PVC pipe 3” • 90° Elbow 3“ • Seashell and gravels • Net pot hydroponics
Money	TOTAL = RM 809.00	TOTAL = RM 1756.50	TOTAL = RM 1777

3.3 Finalized design

The design shows in Figure 4 is the final design of the project. The design was selected after the comparison was done based on morphology analysis which consists of the elements of manpower, machine, material and money. Figure 5 shows the finalized design of this project. This design was selected because it presents information in an organized manner and is simple for people to navigate. In addition, the cost of its design is the lowest as compare to concept 2 and concept 3. The number of plant units that can be grown in it is extremely high, at 76 separate plant units.

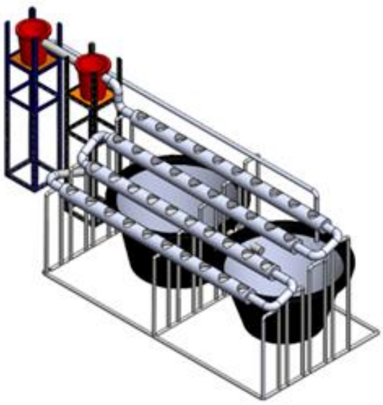


Figure 2: The finalized design

3.4 Process Flowchart

The figure 3 shows the process flowchart of the aquaponic system.

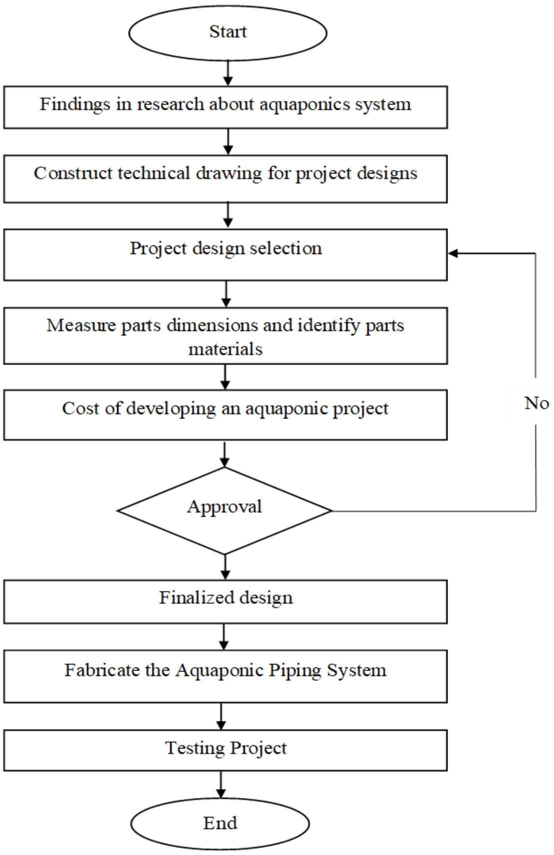


Figure 3: Process Flowchart for Aquaponics System

3.5 Fabrication Result

In order to establish a project, it's essential to thoroughly research the development technique that will be employed. It is possible to conduct tests to determine whether or not the system is stable and secure enough to be implemented. In order to ensure the safety of its users, and since it must be done properly, this testing is vital. As a result, a strong and solid project structure is required to ensure the success of this testing process. To properly finish the testing and development process, a number of steps must be taken. In addition to measuring and cutting, there is also shape and framing of the system. The overall fabrication step is shown as in Figure 4.

a) Measuring process **b) Cutting process** **c) Drilling process** **d) Shape and Frame**

4. Result and Discussion

4.1 Fabrication Result

The productivity and long-term sustainability of this aquaponics system were significantly improved as a direct result of the morphological study's contribution, which consisted of the selection of the design to be finished. This phase of the production process is finished on schedule. Figure 5 shows the front view and side view of the fabricate result.

Front View **Side View**

4.2 Testing Result

Following the conclusion of the process of building an aquaponics system, the water that is circulated inside this system functions well, and it is risk-free to use since there are no leaks, as shown in Figure 12. It takes roughly 55 to 60 seconds for the cycle to finish completely. The flow in the hydroponic unit is seen in Figure 6.

Figure 6: The flow in hydroponic unit

As a result of this project for 2 weeks, these fish were managed to grow by 0.75 – 0.85 inch. These fish were fed twice a day and managed to keep growing. In order to guarantee that the fish in the tank are in excellent health, it is important to check the water quality in the tank on a regular basis. Figure 13 shows the growth of fish.

Figure 7: Growth of fish after 2 weeks

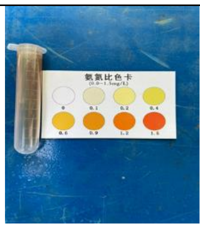
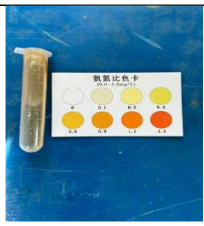
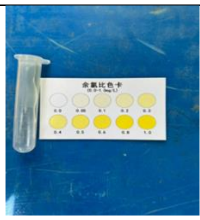
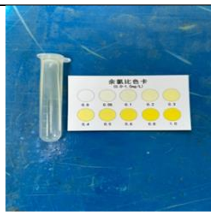
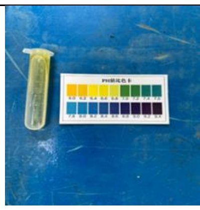
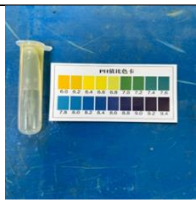
The growth of the plants was taken after 2 weeks. The three types of plant that were lettuce, spinach and basil. These plants were grown to 7.87 to 7.96 inches. These plants grown without the use of any chemical fertilizers and instead rely on nutrients that that have been biofiltered from waste produce by the fishes. Figure 8 shows the growth of plants after 2 weeks.

Figure 8: Growth of plants after 2 weeks

4.3 Water quality testing

In order to keep plants fertile, it is necessary to conduct quality checks of the water on a regular basis. The levels of plant fertility may be influenced by the presence of ammonia and nitrite in the nutrients that are created by fish waste. Because of this, it is essential to make use of biofilters in order to bring down the levels of ammonia and nitrite in plants. In order to determine the amounts of ammonia, nitrite, and pH value, three different kinds of tests were carried out. It is measured once every three days for a total of three weeks while it is in operation. A water quality test kit was used for each of the three tests that were carried out.

Table 3: Water quality test and result

Water quality test	Result
Ammonia test of fish tank 1	
Ammonia test of fish tank 2	
Nitrate test of fish tank 1	
Nitrate test of fish tank 2	
pH value of fish tank 1	
pH value of fish tank 2	

4.4 Water quality of fish tank 1

Table 4: Water quality of fish tank 1

Date	Ammonia (ppm)	Nitrate (ppm)	pH value
12/12/22	0.1	0.05	6
15/12/22	0.1	0.05	6
18/12/22	0.2	0.1	6
21/12/22	0.2	0.1	6
24/12/22	0.3	0.2	6
27/12/22	0.4	0.3	6
30/12/22	0.2	0.1	7

The water quality data for fish tank 1 was recorded every three 3 days for a total 3 weeks and present as in Table 4. The results of the first and second testing showed that reading of ammonia was 0.1ppm and nitrate was 0. 05ppm.It was because the size of fish in the fish tank 1 was small and prevented them from consuming pallets at a high rate, which led to low ammonia and nitrite concentrations at the beginning of the test. As a result, the amount of waste produced from fish remains negligible. While insufficient, the nutrients are nevertheless sufficient for distribution to the plant units. The levels of ammonia and nitrite both rose in the third test, with the ammonia reading reaching 0.2 ppm and the nitrite reading reaching 0.1 ppm. On the fourth day, the ammonia and nitrate levels still remain same while in the fifth day both were increased, ammonia was 0.4 ppm and the nitrate level were 0.3 ppm. In the sixth day, the ammonia level was 0.2 ppm and nitrate level were 0.1 ppm which seemed decrease due to the filtration in an aquaponics system contains bacteria that consume ammonia and nitrite. Throughout the period of the project, the pH level of the water progressively became more neutral, moving from an acidic value at the beginning of the first and second tests, which was a value of 6, to a neutral value on the third and subsequent tests, which was a value of 7. Figure 9 shows the fish tank 1 graph reading for the water quality.

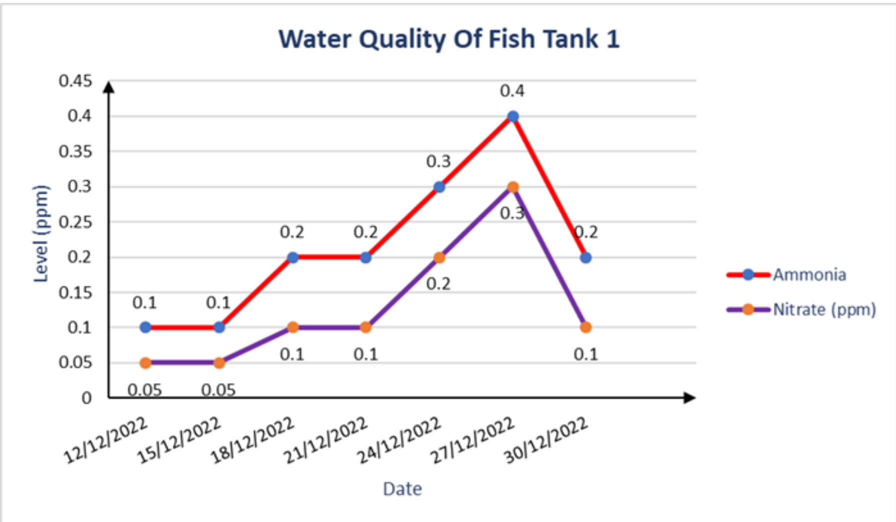


Figure 9: Fish tank 1 of graph reading for the water quality

4.5 Water quality of fish tank 2

Table 5: Water quality of fish tank 2

Date	Ammonia (ppm)	Nitrate (ppm)	pH value
12/12/22	0.1	0.05	6
15/12/22	0.1	0.05	6
18/12/22	0.1	0.05	6
21/12/22	0.2	0.1	6
24/12/22	0.2	0.1	6
27/12/22	0.3	0.2	6
30/12/22	0.2	0.1	7

In the fish tank 2, there is not so much different compare to fish tank 1. The results of the first to third testing showed that reading of ammonia was 0.1ppm and nitrate was 0.05ppm and shown as in Table 5. It was because the size of fish in the fish tank 2 was small and prevented them from consuming pallets at a high rate, which led to low ammonia and nitrite concentrations at the beginning of the test. As a result, the amount of waste produced from fish remains low. Therefore, the nutrients are nevertheless sufficient for distribution to the plant units. The levels of ammonia and nitrite both rose in the third test, with the ammonia reading reaching 0.2 ppm and the nitrite reading reaching 0.1 ppm. On the fourth day, the ammonia and nitrate levels still remain same while in the fifth day both were increased, ammonia was 0.3 ppm and the nitrate level were 0.2 ppm. In the sixth day, the ammonia level was 0.2 ppm and nitrate level were 0.1 ppm which seemed decrease due to in an aquaponics system, the filtering process utilizes bacteria that are able to break down ammonia and nitrite. Throughout the duration of the project, the pH level of the water gradually became more neutral, shifting from an acidic value at the beginning of the first and second tests, which was a value of 6, to a neutral value on the third and subsequent tests, which was a value of 7. In other words, the water went from having an acidic value of 6 to having a neutral value of 7 over the course of the project. Figure 10 shows the small tank graph reading for the water quality.

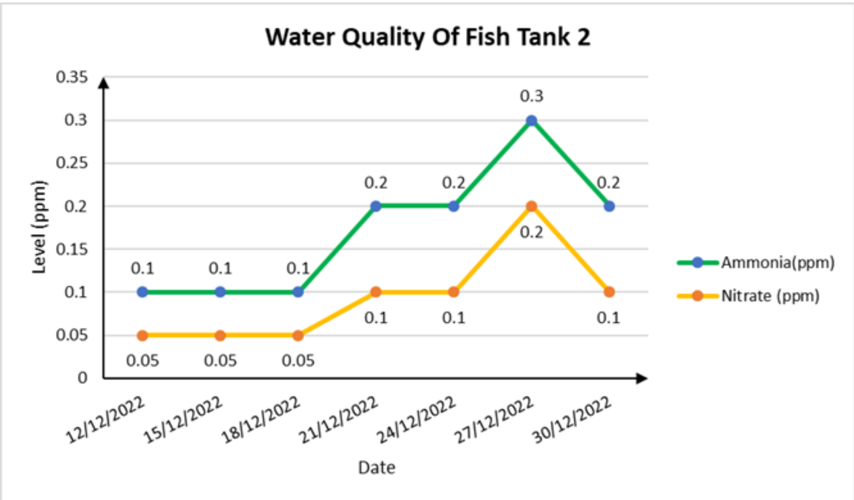


Figure 10: Fish tank 2 of graph reading for the water quality

5. Conclusion

In conclusion, the design and development of aquaponics piping system for urban farming is a remarkable innovation that has enormous positive implications for the farming sector. The project is about aquaponics and the piping system which is playing major role on it. This is because, the water is running through the pipes and reach to the fish and plants. If the pipes are broken or get water leaked, the whole system will shut down. This project has been built with a reasonable price as it as many piping and fittings equipment as well as filters. This project used a Nutrient Film Technique (NFT) hydroponic technique where in a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated past the bare roots of plants in a watertight gully. The finalized design is functioning very well with good flowrate of water in the piping system. The plants are getting the proper nutrients and fish have clean water to live in as the water quality parameters are maintaining well. The operation of the system was subject to stringent regulation throughout the whole of the production process. This is the case due to the fact that the operator is in a position to identify both the strengths and weaknesses of the system during the whole process of choosing and analyzing applicants. In addition to this, the operator is allowed to adjust the scale and size of the available resources as necessary to ensure that they are suitable for the development site. The thoughtful selection of equipment is yet another component that contributes to the proper functioning of an aquaponic system. In order to ensure the long-term viability of the system, selecting a biofilter unit is another crucial step. It achieves its purpose by filtering away both the nutrients and the poor quality of the water that the plants absorb. We need to make sure that the filter unit that comes with this biofilter is safe to use before we can put it to good use. Before putting it to use in this aquaponic system, we have the ability to take charge and perform our own research and tests. This experiment may be carried out by placing the fish in a separate container and allowing it to remain there for a day. After that, we can channel the water through a separate filter unit and use a test kit to determine the amount of ammonia and nitrite present. If the reading is satisfactory, the filtration system may be used without risk. Last but not least, for the upgradation, we can add more row of pipes for the hydroponics system to get more plants. To save electricity costs, we can use photovoltaic power if at all possible and selecting efficient pumps.

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References

[1] Satterthwaite D, McGranahan G, Tacoli C. (2010). Urbanization and its implications for food and farming. Philos Trans R Soc Lond B Biol Sci. 2010 Sep 27;365(1554):2809-20. doi: 10.1098/rstb.2010.0136. PMID: 20713386; PMCID: PMC2935117.

[2] Hendrickson, M. K., & Porth, M. (2012). Urban agriculture—best practices and possibilities. University of Missouri, 1-52.

[3] Stewart, R., Korth, M., Langer, L., Rafferty, S., Da Silva, N. R., & van Rooyen, C. (2013). What are the impacts of urban agriculture programs on food security in low and middle-income countries? Environmental Evidence, 2(1), 1-13.

[4] The World Bank, 2015. Urban Development. [Online] Available at: http://www.worldbank.org/en/topic/urbandevelopment/overview [Accessed 1 April 2016].

[5] Pattillo, D. A. (2017). An overview of aquaponic systems: hydroponic components.

[6] Connolly, K., & Trebic, T. (2010). Optimization of a backyard aquaponic food production system.

[7] Nelson, R. L. (2008). Aquaponic equipment: the biofilter. Aquaponic J, 48(2), 22-23.

[8] Miller, C. (2015). Automated Aquaponics Design Report.

[9] Bracino, A. A., Española, J. L., Bandala, A. A., Dadios, E. P., Sybingco, E., & Vicerra, R. R. P. (2021). Optimization of biofilter size for aquaponics using genetic algorithm. Journal of Advanced Computational Intelligence and Intelligent Informatics, 25(5), 632-638.

[10] Mohapatra, B. C., Chandan, N. K., Panda, S. K., Majhi, D., & Pillai, B. R. (2020). Design and development of a portable and streamlined nutrient film technique (NFT) aquaponic system. Aquacultural Engineering, 90, 102100.

[11] Lennard, W. A., & Leonard, B. V. (2004). A comparison of reciprocating flow versus constant flow in an integrated, gravel bed, aquaponic test system. *Aquaculture International*, *12*(6), 539-553.

[12] Diver, S. 2006. Aquaponics—integration of hydroponics with aquaculture. Amy Smith, Production. A Publication of ATTRA— National Sustainable Agriculture Information Service. Retrieved from: www.attra.ncat.org

[13] Underwood, J., & Dunn, B. (2016). Aquaponics. Oklahoma Cooperative Extension Service.

[14] Bernstein, S. (2011). *Aquaponic gardening: a step-by-step guide to raising vegetables and fish together*. New society publishers.

[15] Pubs.nmsu.edu. 2022. Important Water Quality Parameters in Aquaponics Systems | New Mexico State University - BE BOLD. Shape the Future.. [online] Available at: <https://pubs.nmsu.edu/_circulars/CR680/index.html> [Accessed 15 June 2022].

[16] Gogreenaquaponics.com. 2022. Tips for Monitoring Water Quality in Aquaponics - Go Green Aquaponics. [online] Available at: <https://gogreenaquaponics.com/blogs/news/aquaponics-maintenance-monitoring-water-quality> [Accessed 15 June 2022