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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 7 weeks. After completing the fabrication process, Anabas Testudineus fish (climbing perch) and Lettuce and Pak Choi plants were added. The levels of ammonia, nitrite, residual chlorine and pH values was collected. Based on the obtain results, the first and second tests showed that the reading rate of ammonia was 0.2 ppm and nitrite was 0.005 ppm. Increases in ammonia and nitrite levels occurred in the third test and continued to increase on the fourth and fifth tests. The decrease in ammonia and nitrite levels returned to stable and decreased beginning on the sixth test and subsequent tests due to the action of ammonia-oxidizing bacteria and nitrite oxidizing bacteria present in the filter media and remained in 0.1 ppm ammonia and 0.010 ppm for nitrite. The pH and residual chlorine values are also at appropriate rates for aquaponic systems. 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.

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Keywords: Aquaponics Nutrient Film Technique, Design Selection, Anabas Testudineus (climbing perch), Lettuce, Pak Choi, Ammonia, Nitrite

1. Introduction

Due to the rapid urbanization and land scarcity, food security is a major concern for most developing country. Aquaponics is a form of food production system that uses circular economy concepts and a biomimetic natural system to reduce input and waste [1]. Aquaponics is a system that seamlessly integrates the farming of hydroponics and aquaculture. This method of farming eliminates the need for large space, time, and manpower. Its continuous recirculation system allows the plants to use the same water source to maintain their optimum growth [2]. This method of urban farming is ideal for sustainable development.

Aside from addressing the food security concerns, implementing an urban agricultural system is also important to achieving a high-quality food supply. Based on studies, there are many agricultural products in the market that do not meet health standards [3]. Through aquaponic systems, the presence of bacterial populations from the fish waste can be turned into plant-based nutrients, which are good for the environment.

A dynamic system model is used to evaluate the various subsystems of an aquaponic system. It involves the use of ball valve and arrangement of pipe position as a control systems and equipment that able to ensure the project's stability and effectiveness [4]. The various water quality parameters, such as ammonia, nitrate, and chlorine, are also monitored using a fresh water test kit.

2. Materials and Methods

2.1 Materials

The main structure of this project is made of PVC pipe and some of its fittings like elbow and tank connector. 2 and 3-inch PVC pipes are used as water flow units and hydroponic plant units. This PVC pipe were cut into several parts according to the measurements on the design that has been sketched before. 380L Tank made of Polyethylene is used to raise fish and 25Litre Bucket is used to place K1 biofilter and 12in1 biofilter. Polyethylene Tank was chosen as the fish tank as it has a yield tensile strength of about 13% higher than that of steel with significantly lesser weight [5]. K1 Biofilter as a mechanical particulate filter and provide a place for the growth of beneficial bacteria, also removes the ammonia and nitrite in the water [6]. Meanwhile, 12in1 Biofilter acts to stabilize the PH value of fish tank and purify water and resist algae growth [4]. The flow system of this project is powered by a 0.75 Hp Centrifugal Pump and its flow is manually controlled by a Ball Valve. The stand used on the biofilter is using a Boltless Rack. Table 1 shows the list of material used in the Aquaponics Piping System.

Table 1: List of Material

a) PVC Pipe

b) Tank Connector

c) Elbow

d) 380L Polyethylene Tank

e) 25Litre Biofiltration Bucket

f) 0.75 HP Centrifugal Pump

g) 12in1 Biofilter

h) K1 Biofilter

i) Boltless Rack

2.2 Design Identification and System

The flow chart as shown in Figure 1 shows the entire process for the design and development of aquaponics piping system for urban farming. The process begins with identification on proper aquaponics systems to be developed in urban areas. After that, construct three technical drawings along with the actual measurements on Solidworks and list the development costs for the three designs concepts. Once completed, make a comparison based on morphology analysis to select the finalized design and after that, the design is ready to be fabricated. After fabrication, the testing process is carried out before it is able to operate properly. Figure 1 shows the design of Aquaponics System Flowchart.

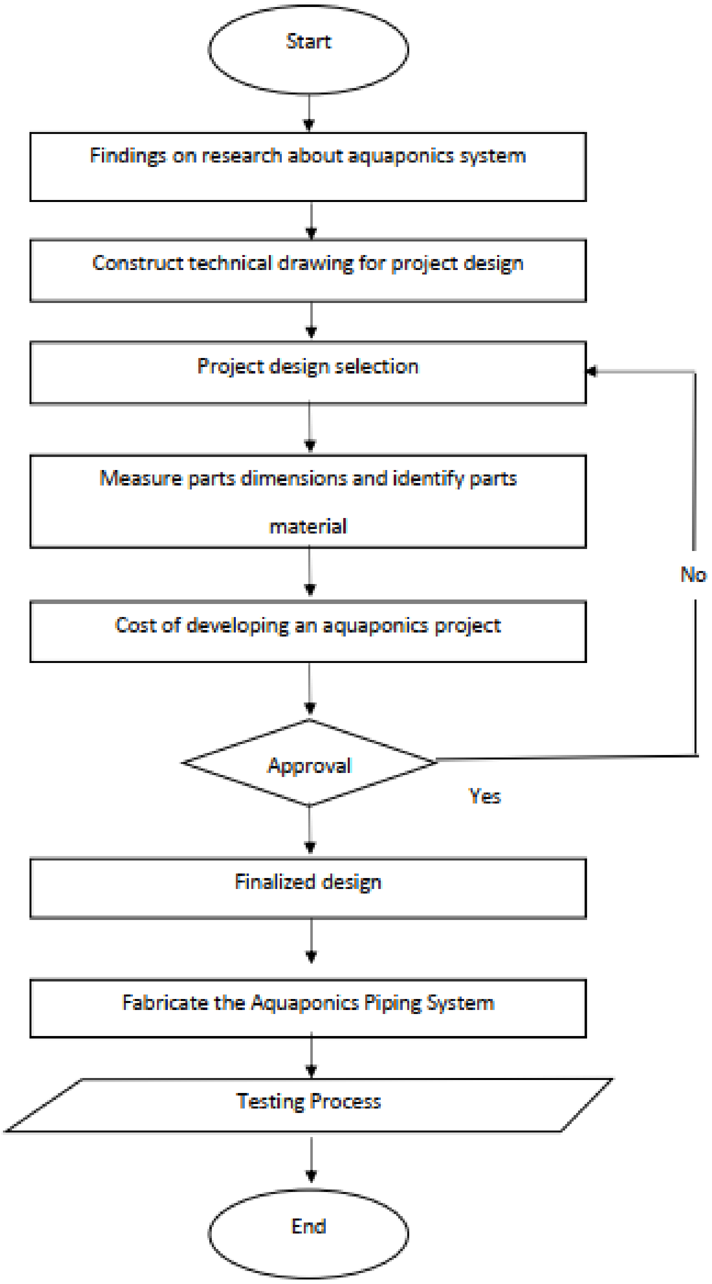

Figure 1: Design of Aquaponics System Flowchart

2.3 Design Selection

It has become a norm, when the design development process, the designer had a tendency of quickly deciding on a single design solution, which is then repeatedly tweaked until a good one is identified [7]. The design shown below is three design concepts that are sketched to select the best design to use in this aquaponics system. The selection of design is important to ensure the flow of water in this aquaponics system is able to operate smoothly and effectively. In addition, comparisons should also be made based on morphology analysis consisting of the elements in manpower, machine, material, and money. Figure 2 – 4 shows the concept design for design selection. Table 2 listed the comparison using morphology analysis.

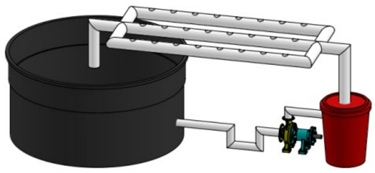

Figure 2: Concept 1

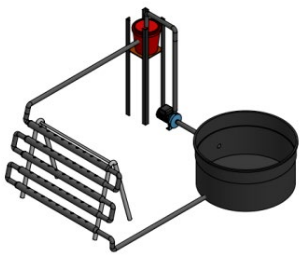

Figure 3: Concept 2

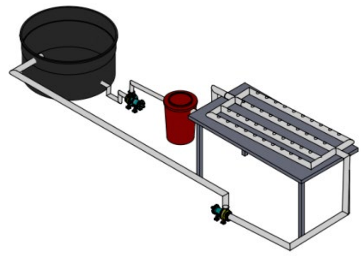

Figure 4: Concept 3

Table 2: Comparison using Morphology Analysis

Element	Concept 1	Concept 2	Concept 3
Manpower	One manpower	One manpower	One manpower
Machine	i. 0.75HP Centrifugal Pump	i. 0.75HP Centrifugal Pump	i. 0.5HP Centrifugal Pump ii. 0.75HP Centrifugal Pump
Material	ii. 380Litre Polyethylene Tank iii. 25Litre Bucket iv. K1 biofilter and 12in1 biofilter (5 kg) v. PVC Pipe 2” (127 cm) vi. PVC Pipe 3” (540 cm) vii. 90° Elbow 2” (5 unit) viii. 90° Elbow 3” (6 unit)	ii. 380L Polyethylene Tank iii. 25L Bucket iv. K1 biofilter and 12in1 biofilter (5 kg) v. PVC Pipe 2” (1200 cm) vi. PVC Pipe 3” (600 cm) vii. 90° Elbow 2” (18 unit) viii. 45° Elbow 2” (3 unit) ix. Tank Connector	iii. 380L Polyethylene Tank iv. 25L Bucket v. K1 biofilter and 12in1 biofilter (5 kg) vi. PVC Pipe 2” (130 cm) vii. PVC Pipe 3” (540 cm) viii. 90° Elbow 2” (5unit) ix. 90° Elbow 3” (6 unit) x. Cross Joint 3” (2unit)

	ix. Cross Joint 3” (2 unit) x. Tank Connector 2” (3 unit) xi. Net Pot Hydroponics (24 unit)	2” (3 unit) x. Ball Valve 2” (1 unit) xi. Pipe Reducing Socket 2”-3” (10 unit) xii. Boltless Rack (1 unit) xiii. Net Pot Hydroponics (40 unit)	xi. Tank Connector 2” (3 unit) xii. Net Pot Hydroponics (40unit)
Money	**Total = RM 704.00**	**Total = RM 858.00**	**Total = RM 990.00**

2.4 Finalized Design

The design shown in Figure 5 is the final design that 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 that used for Aquaponics Piping System.

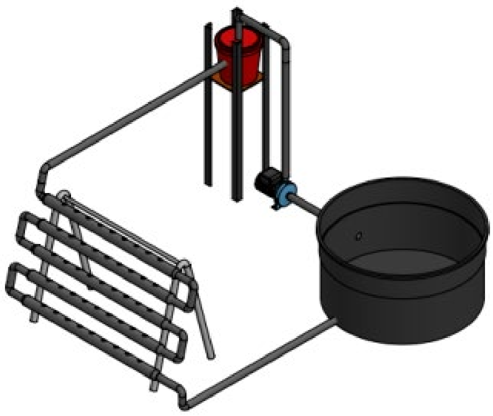

Figure 5: The finalized Design

This design was chosen because of its orderly positioning and easy to access by the users. In addition, the cost for its construction is also the average of the three design concepts produced and the units for growing plants are also quite a lot, 40 units of plants.

2.5 Process Flowchart

The Figure 6 shows the flowchart that describes the processes in the aquaponics system.

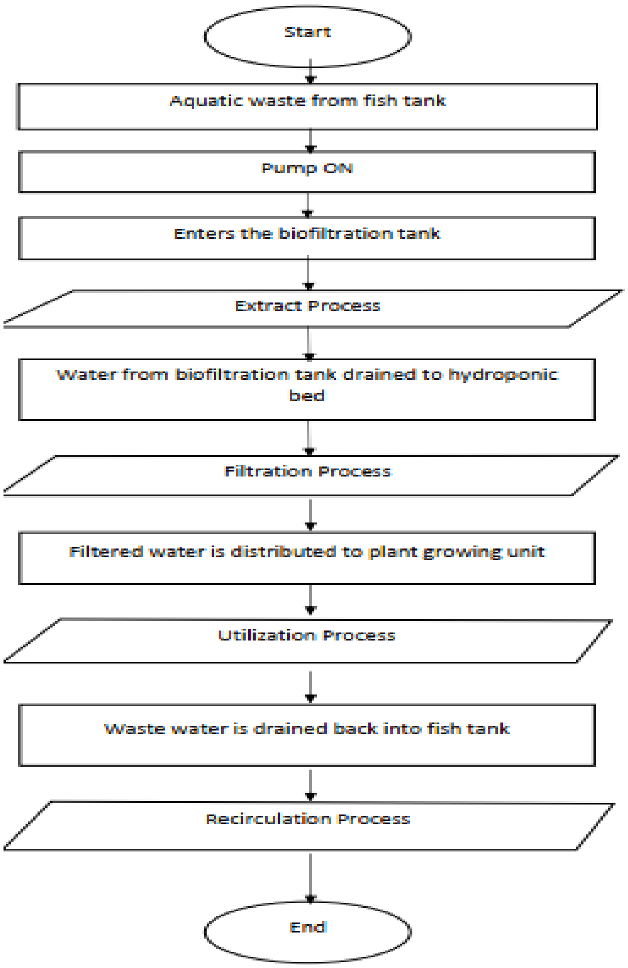

Figure 6: Process Flowchart for Aquaponics System

2.6 Fabrication

This process is very important to study the development methods that will be done to produce a project. The testing process is important to get a project structure that has security and stability [8]. In the fabrication process, there are several steps that need to be taken. Among them are the measurement and cutting process, drilling process, shape and framing process, and installation process.

The first step that needs to be done in this fabrication process is to mark the measurement as developed in Solidworks. This marking should have a slight gap to spare some tolerance for the next cutting process. The process of cutting the pipe is by using a hand grinder.

The next step is the drilling process. The process of making these holes is done on hydroponic pipes to place the plants unit and on tanks that to be connected with pipes. This process uses a bench drilling machine and hand drill. After completing the following steps, the shape and framing process is developed using 45 ° and 90 ° elbows. It needs to be framed first to check its accuracy as in the design. Figure 7 – 10 shows the fabrication process that included the measuring, cutting, drilling, shape and framing process.

Figure 7: Measuring process

Figure 8: Cutting process

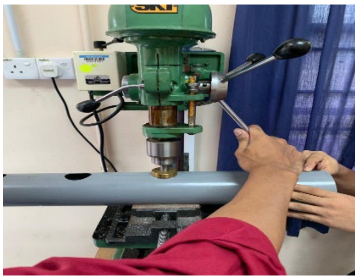

Figure 9: Drilling process

Figure 10: Shape and Framing process

The final step for this fabrication process is the process of installing pipes on the equipment used such as water tanks, biofilter tanks, pumps, and hydroponic units. These pipes need to be installed tightly and neatly using glue to prevent any leakage. After all the installation is completed, the project is ready to run effectively and safely. Figure 11- 12 shows the installation and attached process.

Figure 11: Installing the pump

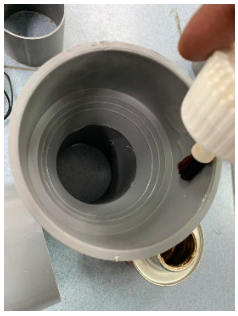

Figure 12: Attach all parts using glue

2.7 Water Quality Testing

In maintaining plants fertility, water quality tests need to be measured frequently. Nutrients produced from fish waste contain ammonia and nitrite which can affect the level of plant fertility. Therefore, the use of biofilters is important to reduce ammonia and nitrite levels in plants. Four types of tests were performed to measure the levels of ammonia, nitrite, residual chlorine, and pH value. It is measured every 3 days for 3 weeks of operation. All four tests were performed using a water quality test kit.

To measure the level of ammonia in this aquaponics system, it has four steps that need to be done before getting the reading. The first step is, take 4ml of water from the fish tank and put it into the tube. The second step is, add four drops of ammonia reagent No. 1 into the tube and shake well. Third step, add four more drops of ammonia reagent No. 2 into the same tube and shake well and wait for up to two minutes. The last step is, match with the color card to get the ammonia reading. Next, the method of measuring nitrite levels in this aquaponics system is almost the same as the method of measuring ammonia levels. However, the method of measuring nitrite levels has only three steps required. The first step is, take 4ml of water from this tank and put it into another tube. Second step, add eight drops of nitrite reagent on the following tube and shake well and wait up to a few minutes. After that, where the last step is to match with the color card to get the nitrite reading.

Next, test to measures the residual level of chlorine in the fish tank. This test is done to ensure the health of the fish. The first step is, take 5ml of water sample from the fish tank and put it into the tube. The second step is to add two drops of chlorine reagent into the tube and shake well. The last step is, match with color card to get the residual chlorine reading. The last test is to measure the pH value. The pH value of this system must be maintained. It is intended to avoid situations where our plants show symptoms of malnutrition. Sometimes, it is not our system that is deficient in minerals, but the pH of the water that causes those nutrients not to be absorbed by plant roots. This pH value is taken on this aquaponics system and matched to the color according to its value. Figure 13 – 16 shows the ammonia, nitrite, residual chlorine, and pH test kit.

Figure 13: Ammonia Test

Figure 14: Nitrite Test

Figure 15: Residual Chlorine Test

Figure 16: pH Value Test

3. Results and Discussion

3.1 Fabrication Results

The selection of the finalized design from the morphology analysis had a great impact on the effectiveness and the sustainability of this aquaponics system. This fabrication process is completed on time. Figure 17 – 18 shows the Aquaponics design from front view and side view.

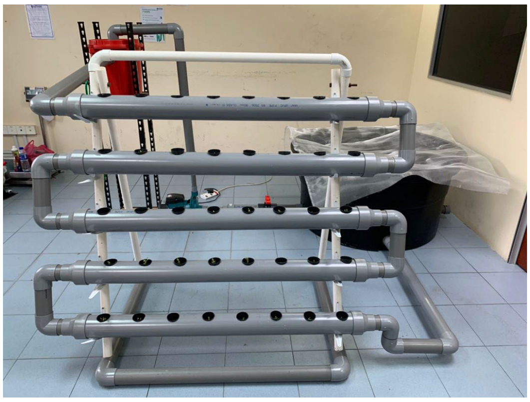

Figure 17: Front View

Figure 18: Side View

3.2 Testing Result

After the completion of developing an Aquaponics system, the water flowing in this system operates well and is safe to use without any leakage as shown in Figure 12. A complete cycle takes about 70 to 80 seconds. Figure 19 shows the flow in hydroponic unit.

Figure 19: The flow in Hydroponic unit

As a result of the operation for 2 weeks, the Anabas Testudineus (climbing perch) managed to grow by ± 1.1 cm which is 6.70 ± 0.57 cm in size as shown in figure 13. This fish was fed twice a day and placed in a Polyethylene Tank. It is managed to keep this Anabas Testudineus (climbing perch) growing and also regularly monitor the water quality in the fish tank to ensure that the fish's health is in good condition. Figure 20 shows the Anabas Testudineus (climbing perch) after 2 weeks.

Figure 20: The Anabas Testudineus (climbing perch) after 2 weeks

The growth rates of the plants were also measured for 2 weeks. The two types of plants that had been used were Pak Choi and Lettuce. These plants were grown to 4.2±0.07 cm for the Lettuce and 5.2±0.02 cm for Pak Choi as shown in Figure 14. These plants grown without the use of chemical fertilizers and rely on bio-filtered nutrients from fish waste. Germination sponge is a medium used as a substitute of soil. Figure 21 shows the Lettuce and Pak Choi in the hydroponic unit after 2 weeks.

Figure 21: Lettuce and Pak Choi after 2 weeks

3.3 Water Quality

To ensure that the water quality is always adequate, the total ammonia, nitrite, residual chlorine, and pH value need to measure regularly [9]. From December 14, 2021, until January 4, 2022 is a sample period that was collected every three days to monitored the level of the nutrient. Table 3 listed the water quality collected for 3 weeks.

Table 3: Water Quality collected for 3 weeks

Date	Ammonia (ppm)	Nitrite (ppm)	Residual Chlorine (ppm)	pH

14/12/2021	0.2	0.005	0	6
17/12/2021	0.2	0.005	0	6
20/12/2021	0.3	0.010	0	7
23/12/2021	0.4	0.050	0	7
26/12/2021	0.4	0.100	0	7
29/12/2021	0.3	0.050	0	7
01/01/2022	0.2	0.050	0	7
04/01/2022	0.1	0.010	0	7

These water quality test data were recorded every 3 days over a 3 -week period. The results of the first and second tests showed that the reading rate of ammonia was 0.2 ppm and nitrite was 0.005 ppm. The factor that caused the low ammonia and nitrite values at the beginning of this test was because the size of the fish used in this system was still small and had not been able to consume pallets at a large rate [5]. Therefore, the waste produced on fish is still in small proportions [5]. However, the nutrients carried are still sufficient to be distributed to the plant units. Increases in ammonia and nitrite levels occurred in the third test where 0.3 ppm at the ammonia value and 0.010 ppm at the nitrite value. These ammonia and nitrite levels continued to increase on the fourth and fifth tests. Ammonia levels on the fourth and fifth tests recorded the highest reading rate of 0.4ppm, while nitrite was 0.050 ppm on the fourth test and 0.100 on the fifth test. The decrease in ammonia and nitrite levels returned to stable and decreased beginning on the sixth test. It is due to the action of ammonia-oxidizing bacteria and nitrite oxidizing bacteria present in the filter media of the aquaponics system [10]. 0.3 ppm of ammonia was recorded on the sixth test, 0.2 ppm on the seventh test, and 0.1 ppm on the eighth test. While 0.050 ppm nitrite on the sixth and seventh tests, and decreased to 0.010 ppm on the eighth test. The pH level of the water gradually increased in this system throughout the trial period, from the 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. While the Residual Chlorine value remained at 0 ppm from the beginning of the test. Figure 22 shows the graph reading for the water quality.

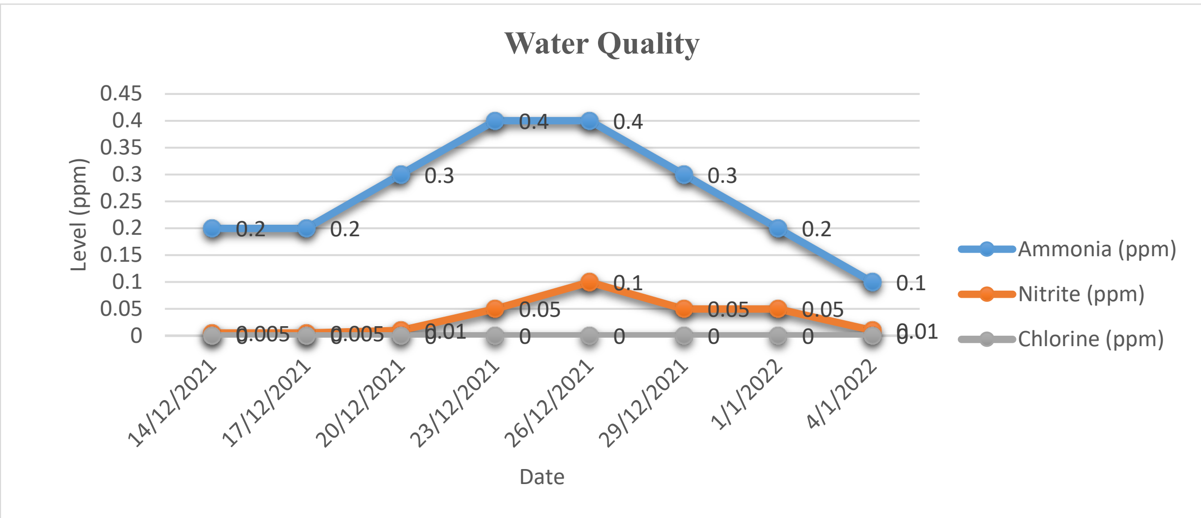

Figure 22: Graph readings for the water quality

This water quality was compared to test data presented by [11]. The aquatic life used is the same species namely Anabas Testudineus (climbing perch) while gravel is used as the filtration unit. Based on the study conducted by them, the readings on the first test showed a rate of 0.5 ppm for ammonia and 0.0 ppm for nitrite. In their second test, the increase in ammonia level occurred up to 1.0 ppm while the nitrite rate was 0.01 ppm. However, a decrease in the rate occurred in the third test where the ammonia rate dropped to 0.6 ppm and nitrite was 0.0 ppm. The fourth test showed a slight increase in ammonia levels of 0.8 ppm and nitrite at 0.01 ppm. The decrease occurred again on the fifth test for ammonia level of 0.4 ppm and increased again sharply on the sixth test of 2.0 ppm ammonia. The nitrite content in the fifth test remained at 0.01 ppm, the same as in the fourth test. However, it also increased in the sixth test at a rate of 0.02 ppm. Based on the author's statement, the levels of ammonia and nitrite began to remain stable starting from the seventh test and onwards at a rate of 0.3 ppm ammonia and 0.02 ppm nitrite.

Aquaponic system provide many specific benefits and advantages to its operators. Among them is that plant yields can reach 10 times more than normal cultivation methods. In other words, a small planting space can produce a lot of yields. This is because each plant root in this system gets a source of nutrient -rich fertilizer water evenly as well as its growth rate is simultaneous. Plant growth is two times faster than conventional cropping methods. It is very suitable for use in the residential yard of a house that is limited in size, especially in urban areas. Apart from that, this system also does not need to do crop watering activities. Only 5.00 % of water consumption is required in aquaponic cultivation compared to above ground cultivation. Gardening work such as weeding, loosening the soil and cultivating is no longer required. Disturbances of soil -borne pests and diseases are also reduced because aquaponic systems do not involve direct land use. All that needs to be done to maintain the aquaponic system is simply to feed the fish two or three times a day and make maintenance every two or three months as well as harvest the produce when it matures.

4. Conclusion

In conclusion, the operation of the system was well-controlled throughout the entire fabrication process. This is because, during the selection and analysis stages, the operator can identify the areas of weakness and effectiveness of the system. In addition, the operator can set the scale and size allocated so that it is appropriate to the area to be developed. The selection of appropriate equipment is also a factor that contributes to the smooth operation of this aquaponic system.

The selection of a biofilter unit is also an important role in the system's sustainability. It carries out its function by filtering the nutrients and water quality for the plants. Before using this biofilter, we should make sure that the filter unit is safe to use. We can take the initiative to conduct our own experiments before use it in this aquaponic system. This experiment can be done in a way, put a fish in a separate container and leave it for a day, and channel it on a separate filter unit and test the level of ammonia and nitrite content using a test kit. If the reading is optimal, then the filter unit is safe to use.

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