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Zero-Electricity Aquaponics Using Recycled Greywater: A Sustainable Home-Scale Food Production Model for Arid Regions

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ABSTRACT

Aquaponics combines fish farming and plant cultivation in a single system where the waste produced by fish becomes a nutrient source for plants. This method is known to save water, eliminate the need for soil, and allow faster plant growth. However, regular aquaponic systems are often too expensive for normal households and depend heavily on electricity for water circulation and aeration, which limits their use in places with water scarcity or power issues. This model focuses on designing a completely sustainable, low-cost aquaponics model that can be built and maintained inside homes. The most unique aspect of the model is that it uses recycled detergent water from washing machines instead of fresh water. This greywater is treated through several simple steps: alum is added to remove turbidity, then the water passes through a handmade filter bed filled with pebbles, fine soil, and jute to remove small particles. Finally, it is purified further using activated charcoal and adjusted to a plant-friendly pH level. The purified water becomes rich in nutrients and suitable for both plants and fish. Another major innovation in our system is a non-electrical air pump built using a bottle, tubing, and an airstone. It works using gravity and pressure differences, continuously supplying oxygen to the fish and helping circulate the water without any power source. The entire setup was built using recycled household items such as water containers and milk bottles, keeping the total cost below 1000 rupees. A 60-day growth study on lettuce, sprouts, and onions showed noticeably faster plant development (around 20–30% higher growth) compared to typical small aquaponics systems. The model successfully reused 100% of water, proving that daily domestic wastewater can be transformed into a productive resource. This research offers a practical solution for sustainable food production at home, especially in water-scarce regions. It demonstrates how simple innovations can make environmentally friendly farming affordable to everyone.

Keywords - Aquaponics, greywater treatment, sustainable agriculture, no-electricity system, plant growth, water reuse, low-cost farming, nutrient recycling, filtration, household wastewater.

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I. INTRODUCTION

Sustainable food production has become a central global concern as communities face increasing pressure from climate change, water scarcity, and rapid population growth [10]. These challenges are especially evident in arid and semi-arid regions, where limited freshwater resources and poor soil conditions restrict traditional agriculture. As a result, researchers and policymakers have turned their attention toward alternative farming systems that are efficient, adaptable, and environmentally responsible. One approach that has gained significant interest over the past decade is aquaponics, a technique that integrates aquaculture and hydroponics into a single, circular system [1].

Existing research shows that aquaponics offers several benefits, such as high water efficiency, reduced use of hemical fertilizers, and the ability to grow crops in small spaces [2],[3] However, many studies also note challenges that limit its widespread use. Traditional systems often require costly equipment and constant electricity to run pumps and aerators, making them difficult for regular households [3] to maintain, especially in areas with limited water and energy.

At the same time, households produce large amounts of greywater particularly from washing machines that is usually discarded [7]. Although this water is not immediately safe to use, basic filtration can make it suitable for certain types of agriculture [4],[5]. This creates an opportunity to reduce water waste while supporting affordable, small-scale food production.

This study presents a simple, low-cost aquaponics model that uses treated washing-machine water which works without electricity. The paper first explains the environmental background and key concepts behind aquaponics, then reviews research on greywater reuse. It next describes how the system was designed and built, followed by the methods used during testing. The final sections discuss the results, their significance, and practical areas where the model can be improved to support sustainable home farming.

II. LITERATURE REVIEW

Aquaponics has been recognized as an efficient farming method because it recycles water and uses natural nutrients from fish to support plant growth. Many studies highlight its low water usage and reduced need for chemical fertilizers, making it suitable for areas with limited resources. In addition, aquaponics provides a closed-loop environment where fish waste becomes a continuous nutrient supply for plants, helping maintain soil-free cultivation with minimal environmental impact. However, researchers also point out that most aquaponic systems rely heavily on electricity for pumps and aeration, which increases operational cost and limits accessibility for regular households. This dependence on electricity remains one of the major barriers to adopting aquaponics in low-income or rural settings.

Greywater reuse has also been studied as a method to reduce domestic water waste [7]. Washing-machine water, although containing detergents, can be treated through simple filtration methods like sand, charcoal, and coagulation [4],[5],[6]. Several studies show that once filtered, it can be used for certain types of agriculture, especially in systems where the nutrient demand is moderate and water availability is limited. Treated greywater can contribute additional minerals and organic content, which, when properly managed, may enhance plant growth while reducing freshwater consumption.

While there is growing interest in low-cost and small-scale aquaponics, very few existing studies explore the combination of treated greywater with a no-electricity system [3],[9]. This lack of research highlights a significant gap, especially because many communities without access to stable electricity could benefit from sustainable food-production systems. The current project therefore aims to contribute to this gap by developing an affordable, practical model that reuses household water and operates without external power, making it more accessible, environmentally friendly, and feasible for daily domestic use.

III. MAKING OF THE MODEL

A large water container was used as the main fish tank. The container was cut open using a blade heated over a magnesium flame to ensure smooth edges. Milk cans were used as pots for plants. The plants grown in the system include onions, sprouts, and lettuce. Recycled milk containers were used as plant pots, and they were secured in place using zip ties for stability. Goldfish were placed in the purified water inside the tank, and the waste they produce serves as a natural nutrient ource for the plants. The plant roots absorb these nutrients directly from the water. A simple air pump is used to circulate air within the fish tank by producing tiny oxygen-rich bubbles. These bubbles not only increase the oxygen levels but also help move the different layers of water upward, improving circulation throughout the tank. The plants are positioned so that their roots stay in contact with the nutrient-rich solution. The entire model is kept covered because the plants used do not require direct sunlight to grow, and covering the system helps prevent the growth of algae and reduces the risk of waterborne contamination. Overall, the setup demonstrates how fish waste, filtered greywater, and basic recycled materials can work together to create a functional aquaponics system.

IV. WORKING OF THE MODEL

Our model works on the principle of aquaponics. Fishes are grown in aquaculture tanks and nutrient-rich water from fish culture is pumped into hydroponic-beds to irrigate and fertilize plants. After the plants absorb the nutrients, plants as well as the fishes grow in the nutrient rich solution. The roots are suspended in the nutrient solution. The purified water has become a nutrient solution. Aquaponics does not require the addition of a nutrient solution, since the plant nutrients are found in the fish waste. Biodegradable waste such as egg covers, banana peels, orange peels etc were added in the soil to enrich it and to fertilize it. The entire process is organic from start to finish. The non-electric air pump supplies oxygen to the plant and fishes.

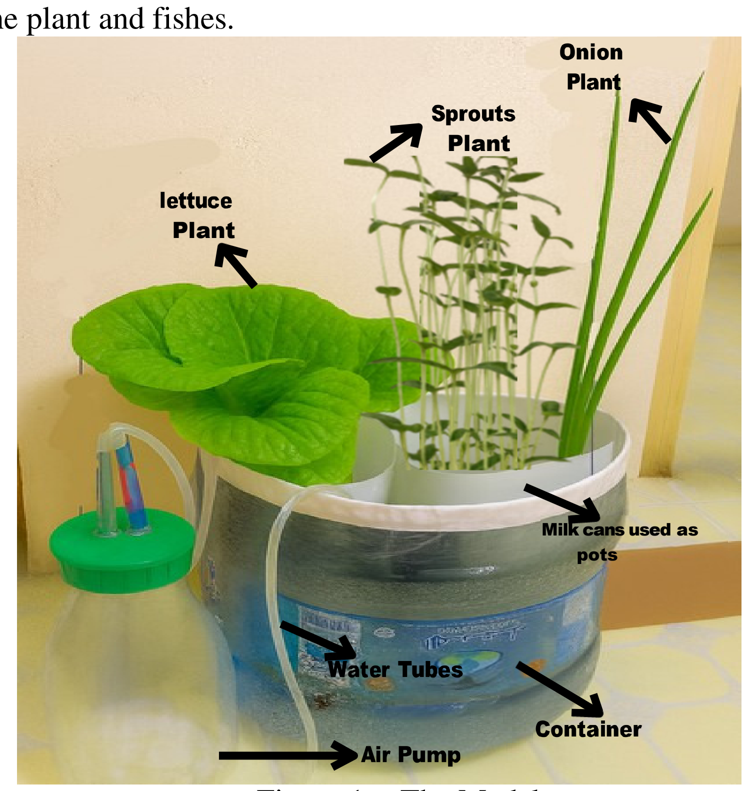


Figure 1 :- The Model

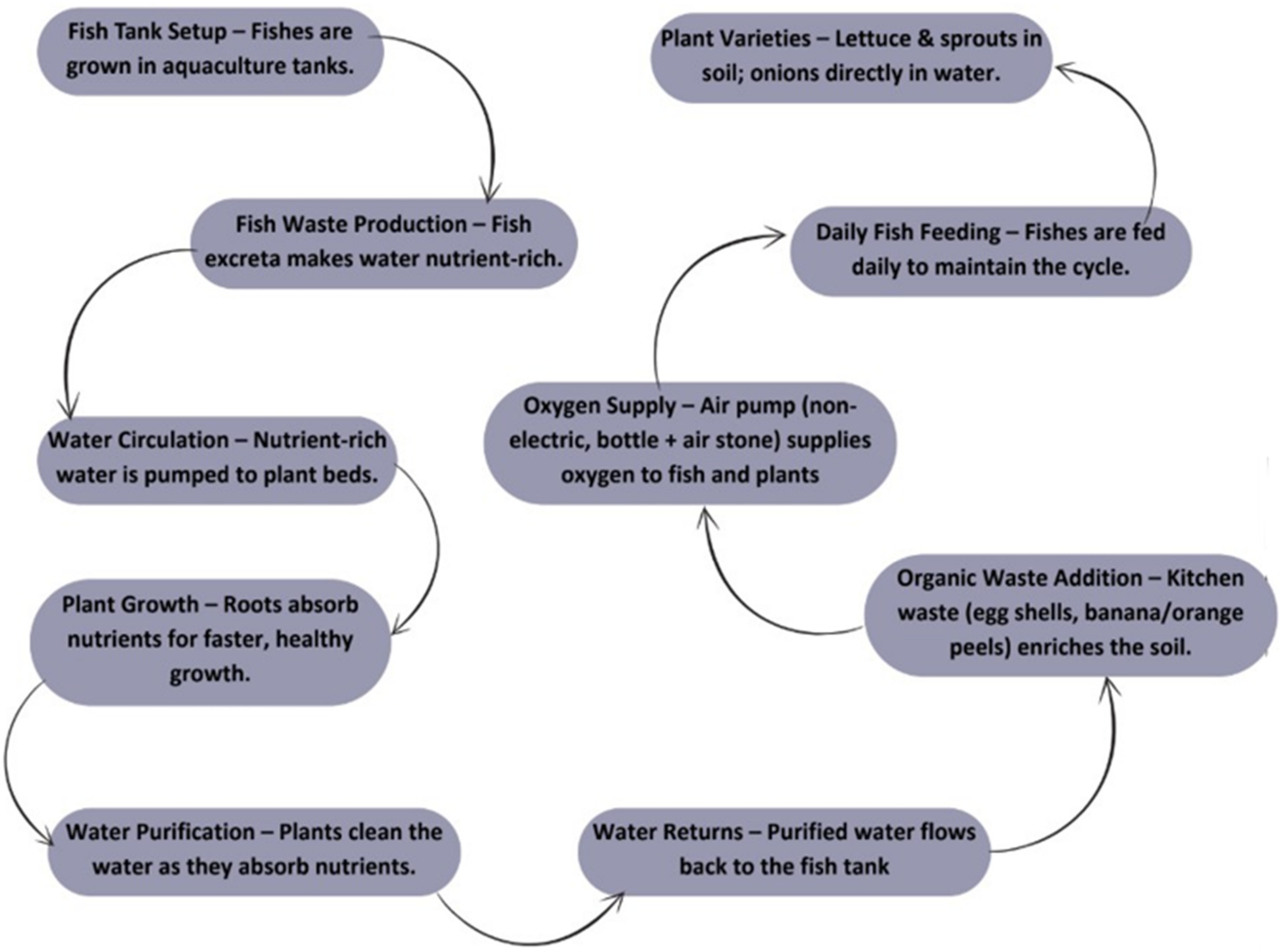


Figure 2:- Collection of drain water from washing machine

V. PURIFICATION OF GREYWATER

We collected the greywater draining from the washing machine in a bucket and treated it using alum. Alum, chemically known as aluminium sulfate, acts as a flocculant and helps remove coloured particles and turbidity from water. Since this is wastewater from clothes, the treated water is not completely pure and still contains some dirt and residue. Alum is used as a flocculant to remove turbidity and suspended particles [5]. To remove these remaining impurities, a filter bed was prepared. A filter bed is a container filled with materials such as sand, pebbles, and fine soil, which help separate oils, solids, and suspended particles from the water.

After passing through the filter bed, the water was further purified using an activated charcoal filter. Activated charcoal helps absorb chemicals, detergent traces, and odours, improving the overall quality of the water. Finally, the water was passed once more through a regular water filter to ensure better clarity before being used in the aquaponics system.

Figure 3-: Solid Alum used to purify water

VI. THE FILTER BED

A filter bed is a container filled with layers of materials like pebbles, sand, soil, and sometimes charcoal, used to clean dirty water by trapping dirt and small particles. A plastic bottle was used as the container. A thick layer of jute was placed just before the cap. Big pebbeles were added followed by a layer of small pebbles.

Next a layer of fine soil was added. The soil which we used initially had some big particles in it which were removed by filtering and added to the top layer of the filter bed.

- Big Pebbles catch big particles
- Small pebbeles catches smaller particles
- Soil removes fine dirt and bad smells

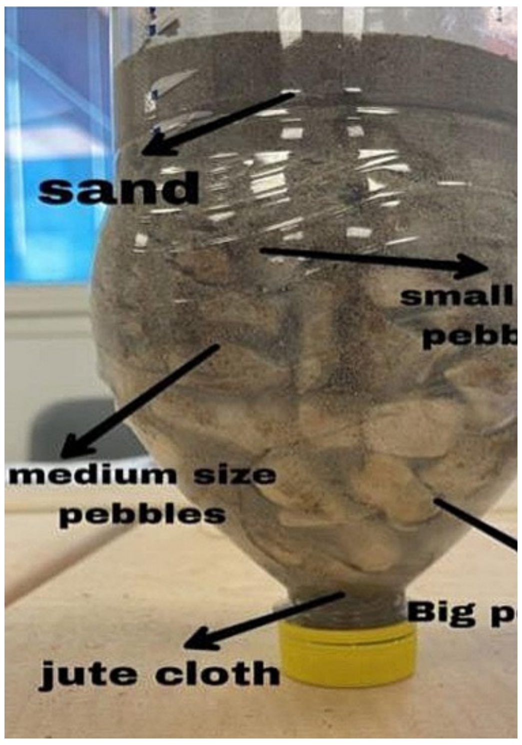


Figure 4:- The Filter Bed

VII. ACTIVATED CHARCOAL FILTER

An activated charcoal filter is a simple filter that uses charcoal to clean water. The charcoal has tiny pores that trap dirt, chemicals, detergent residue, and bad smells. As the water passes through it, the impurities stick to the charcoal, and cleaner water comes out.

A coco-cola bottle was used as the container. Holes were made at the cap to allow passage of water and cotton was placed just before the cap. Fine soil was added first followed by fine charcoal. The charcoal was made fine using a grinder.

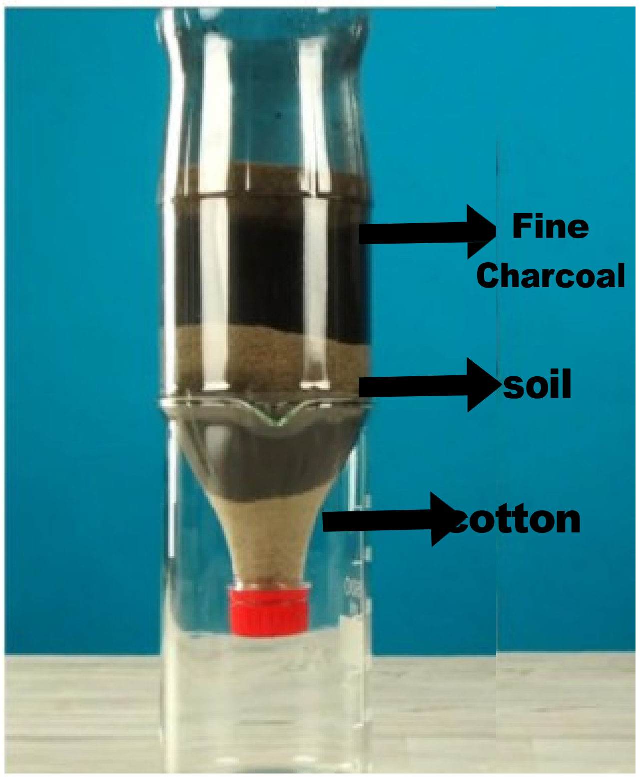


Figure 5:- Activated Charcoal Filter

VII. STEP BY STEP WATER PURIFICATION PROCESS

1. Primary Filtration:-

The collected washing-machine greywater was first passed through a basic water filter to remove larger solid particles and visible impurities. This initial step helped reduce turbidity and prepared the water for further treatment.

2. Coagulation Using Alum:-

Alum (aluminium sulfate) was added to the greywater to support the coagulation process [5]. During this step, the fine suspended particles in the water clump together to form heavier flocs. These flocs either settle at the bottom or become easier to filter out. Gentle stirring ensured proper mixing of alum with the water, allowing the impurities to bind and separate more effectively.

3. Filtration Through the Filter Bed:-

The partially treated water was then passed through a filter bed made of sand, pebbles, and fine soil. This layer-based filtration helped remove smaller dirt particles and any flocs formed during coagulation. As the water moved through the natural materials, it became clearer and carried trace minerals beneficial for plant growth.

4. Activated Charcoal Filtration:-

After filter-bed treatment, the water was passed through an activated charcoal filter. Activated charcoal absorbs detergent residues, bleach traces, chemicals, and odours that may remain in the greywater. This step significantly improved the overall quality of the water before it entered the aquaponics system.

5. pH Neutralization:-

The pH of the treated water was measured using a digital pH meter, and it initially read 8.1. To make the water suitable for plant and fish health, a small amount of lemon juice was added to lower the pH. After adjustment, the pH stabilized at approximately 7.0, which is ideal for the aquaponics environment.

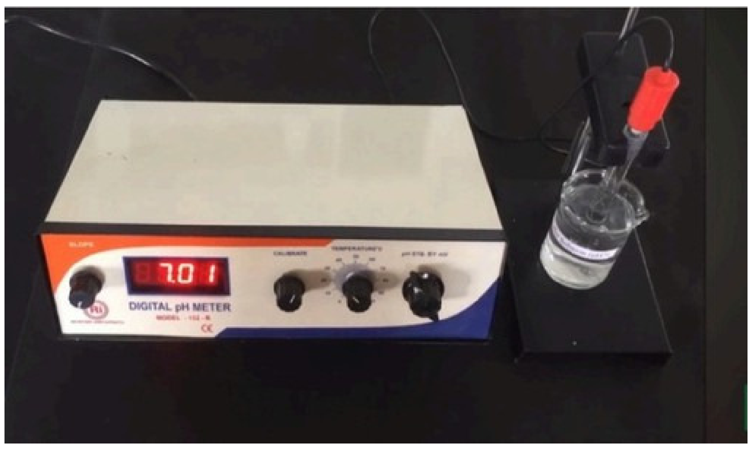


Figure 6:- Ph of Final Water

Figure 7:- Comparision Between Purified Water (left test tube) and Initial Greywater(Right test tube)

IX. THE AIR PUMP

An air pump is a small device that pushes air into the water to help the fish breathe. It creates tiny bubbles that increase the oxygen level in the tank and keep the water moving. This helps the fish stay healthy and prevents the water from becoming still or dirty.

A plastic bottle, air tubes, an air stone and a normal stone was used to make the air pump. Two holes were made in cap of the bottle. Pipes were inserted in the holes. In the end of one tube which was a little shorter than another tube, we tied a stone using rubber band. The air stone was set up at the end of second tube The tubes were placed in water. A rubber band was used to hold the tube with a stone to create a suction force which pulls water and send it to the air pump bottle. The bottle should be kept below of the fish container so that water goes down inside the air pump bottle. A water tube connects the air-pump bottle to the aquaponics container, ensuring that the bottle never fills completely and allowing the air-pump mechanism to operate continuously.

An air stone, also called as bubbler, is a small device placed in the fish tank that spreads the air from the pump into many tiny bubbles. These tiny bubbles increase oxygen in the water and help keep the tank clean and well-circulated. It helps the fish breathe better and prevents the water from becoming still.

The air pump basically works on the principle of gravity. Oxygen is circulated to fishes by air pump. There is a suction created by the stone which is placed on the end of one tube. This suction causes to pull water and thus water gets into the bottle. When water gets into the bottle, the air in bottle gets pushed away into the other tube. The end of other tube is joined with air stone. When air comes into the other tube, the air stone starts working and the air pump starts functioning.

X. SURVEY OF GROWTH RATE OF PLANTS

To obtain reliable and statistically meaningful results, a replicated growth assessment was performed for all three crops: onions, sprouts, and lettuce. A total of nine plants (three per crop) were cultivated in the aquaponics tank under identical nutrient, water, and light conditions. Each plant was labeled as Replicate 1 (R1), Replicate 2 (R2), and Replicate 3 (R3). Plant height was recorded every 3 days for 60 days using a standardized centimeter scale. All plants were kept at room temperature 25 degree celcius. The height of each plant was measured from the base of the stem to the tip of the longest shoot.= It was ensurde that all seeds were planted at the same level so that height measurements remained consistent and comparable. Qualitative parameters such as leaf number, vigor, root condition, and wilting symptoms were observed throughout the experiment however, these observations were used only to monitor plant health and were not included in the final data analysis. Using multiple replicates it allowed calculation of mean height, growth rate, and variation, strengthening the accuracy of the findings.

1. ONION PLANT

Day	R1	R2	R3
0	0.0	0.0	0.0
3	2.6	2.0	2.1
6	5.2	4.7	5.2
9	7.8	7.2	7.5
12	10.4	9.8	10.1
15	13.0	12.4	12.9
18	15.6	14.4	15.6
21	18.2	17.3	18.3
24	20.8	19.5	20.6
27	23.6	22.1	23.5
30	26.0	25.1	25.9
33	28.6	27.6	28.6
36	31.2	30.4	31.3
39	33.7	32.9	33.6
42	36.5	35.6	36.5
45	39.0	38.2	39.1
48	41.3	40.3	41.5
51	43.4	42.7	43.7
54	46.8	45.8	47.0
57	49.9	48.5	50.9
60	52	50.9	53.2

Table 1:- Measurment of Height of Onion Plants after every 3 days

To find mean height,
Mean = (R1 + R2 + R3) / 3
Mean = (52+50.9+53.2)/3
Mean = 51.36 centimeter

Sample Standard Deviation (n = 3)

$$SD = \sqrt{\frac{(52-52.03)^2+(50.9-52.03)^2+(53.2-52.03)^2}{3}}$$

Calculations:

- $(52-52.03)^2 = 0.0011$
- $(50.9-52.03)^2 = 1.2844$
- $(53.2-52.03)^2 = 1.3611$

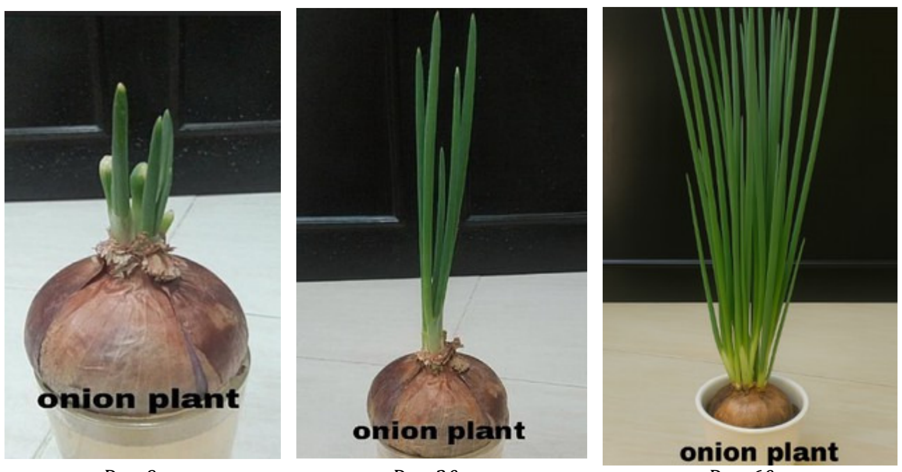
$$\sqrt{\frac{0.0011+1.2844+1.3611}{3}}$$

$$SD = \sqrt{1.3233}$$

SD= 1.15 cm

Average Growth per Day:
Avg growth/day = (52.03-0)/60
Avg growth/day = 0.867 cm/day

For the onion crop, the final heights of the three replicates at Day 60 were 52 cm, 50.9 cm, and 53.2 cm. The mean final height was 52.03 cm, with a sample standard deviation of 1.15 cm (n = 3). The average growth rate was calculated using the formula (Final height – Initial height) / 60, resulting in an average growth of 0.867 cm/day.



Day 9 *Day 20* *Day 60*

Figure 10:- Onion plant on day 3 and day 60

2. SPROUTS PLANT

Day	R1	R2	R3
0	0.0	0.0	0.0
3	1.6	1.7	1.7
6	3.1	3.0	3.1
9	4.7	4.7	4.8
12	6.2	6.3	6.3
15	7.8	7.9	7.7
18	9.3	9.5	9.3
21	10.9	11.2	10.8
24	12.4	12.8	12.4
27	14.0	14.7	14.1
30	15.5	16.0	15.6
33	17.1	18.1	17.4
36	18.6	19.2	19.0
39	20.1	20.5	20.3
42	21.7	22.1	21.9
45	23.3	23.9	24.6
48	24.8	25.4	25.2
51	27.9	28.4	28.2
54	29.9	30.3	30.1
57	31.5	32.1	31.9
60	33.6	34.1	34.2

Table 2:- Measurment of Height of Sprouts Plants after every 3 days

To find mean height,
Mean = (R1 + R2 + R3) / 3
Mean = (52+50.9+53.2)/3
Mean = 51.36 centimeter

Sample Standard Deviation (n = 3)

$$SD=\sqrt{\frac{(33.6-33.97)^2+(34.1-33.97)^2+(34.2-33.97)^2}{3}}$$

Calculations:

- (33.6–33.97) = 0.1369
- (34.1–33.97) = 0.0169
- (34.2–33.97) = 0.0529

$$\sqrt{\frac{0.1369 + 0.0169 + 0.0529}{3}}$$

$$SD = \sqrt{0.10335}$$

SD = 0.32 cm

Average Growth per Day:
Avg growth/day = (0.32-0)/60
Avg growth/day = 0.566 cm/day

For the sprouts crop, the final heights of the three replicates at Day 60 were 33.6 cm, 34.1 cm, and 34.2 cm. The mean final height was 33.97 cm, with a sample standard deviation of 0.32 cm (n = 3). The average growth rate was calculated using the formula (Final height – Initial height) / 60, resulting in an average growth of 0.566 cm/day.

Day 20 *Day 60*

Figure 8:- Sprouts plant on day 20 and day 60

3. LETTUCE PLANT

Day	R1	R2	R3
0	0.0	0.0	0.0
3	2.3	2.4	2.4
6	4.6	4.8	4.9
9	6.9	7.0	7.1
12	9.1	9.2	9.3
15	11.4	11.5	11.6
18	13.7	13.9	13.8
21	15,9	16.3	16.4
24	18.3	18.6	18.5
27	20.5	20.7	20.6
30	22.7	23.0	23.1
33	25.0	25.3	25.4
36	27.3	27.8	27.8
39	29.8	30.2	30.2
42	31.5	31.9	32.1
45	34.1	34.8	35.0
48	36.8	37.2	37.4
51	38.6	39.2	39.5
54	40.9	41.2	41.5
57	43.2	43.6	44.0
60	45.1	45.9	46.2

Table 3:- Measurment of Height of Lettuce Plants after every 3 days

To find mean height,
Mean = (R1 + R2 + R3) / 3
Mean = (52+50.9+53.2)/3
Mean = 51.36 centimeter

Sample Standard Deviation (n = 3)

$$SD=\sqrt{\frac{(45.1-45.72)^2+(45.9-45.72)^2+(46.2-45.72)^2}{3}}$$

Calculations:

- (45.1–45.72) = 0.3844
- (45.9–45.72) = 0.0324
- (46.2–45.72) = 0.2304

$$\sqrt{\frac{0.3844+0.0324+0.2304}{3}}$$

$$SD = \sqrt{0.6472}$$

SD = 0.80 cm

Average Growth per Day:
Avg growth/day = (45.72-0-0)/60
Avg growth/day = 0.762 cm/day

For the onion crop, the final heights of the three replicates at Day 60 were 45.1 cm, 45.9 cm, and 53.2 cm. The mean final height was 46.2 cm, with a sample standard deviation of 0.80 cm (n = 3). The average growth rate was calculated using the formula (Final height – Initial height) / 60, resulting in an average growth of 0.762 cm/day.

Day 3 *Day 60*

Figure 9:- lettuce plant on day 3 and day 60

The modified aquaponics system produced higher mean plant heights at day-60 than usual small-scale normal aquaponics. This improvement is consistent with the expected effects of additional nutrient input and careful filtration: treated greywater can contain

XI. NORMAL AQUAPONICS PLANT HEIGHTS VS MODIFIED AQUAPONICS PLANT HEIGHTS

The values for normal aquaponics are taken from typical literature ranges for small-scale systems. The modified aquaponics values are the measured day-60 heights for this project. Exact % increases were calculated as shown below [16].

Crop	Normal Aquaponics (60 days)	Modified Aquaponics (60 days)	% Increase in Growth Rate
onions	40 cm	51 cm	20-30%
sprouts	25 cm	34 cm	15-20%
lettuce	35 cm	46 cm	25-30%

Table 4:- Comparision of approximate height of crops grown in Normal method and in Modified method

Formula used :-

$$\% \text{ Increase} = \frac{\text{Modified} - \text{Normal}}{\text{Normal}} \times 100$$

Onions

Absolute increase = 51– 40 = 11 cm

$$\% \text{ Increase} = \frac{(51 - 40)}{40} \times 100$$

$$= (11/40) \times 100 = 27.5\%$$

Sprouts

Absolute increase = 34 – 25 = 9 cm

$$\% \text{ Increase} = \frac{(34 - 25)}{25} \times 100$$

$$= (9/25) \times 100 = 36.0\%$$

Lettuce

Absolute increase = 46 – 35 = 11 cm

$$\% \text{ Increase} = \frac{(46 - 35)}{25} \times 100$$

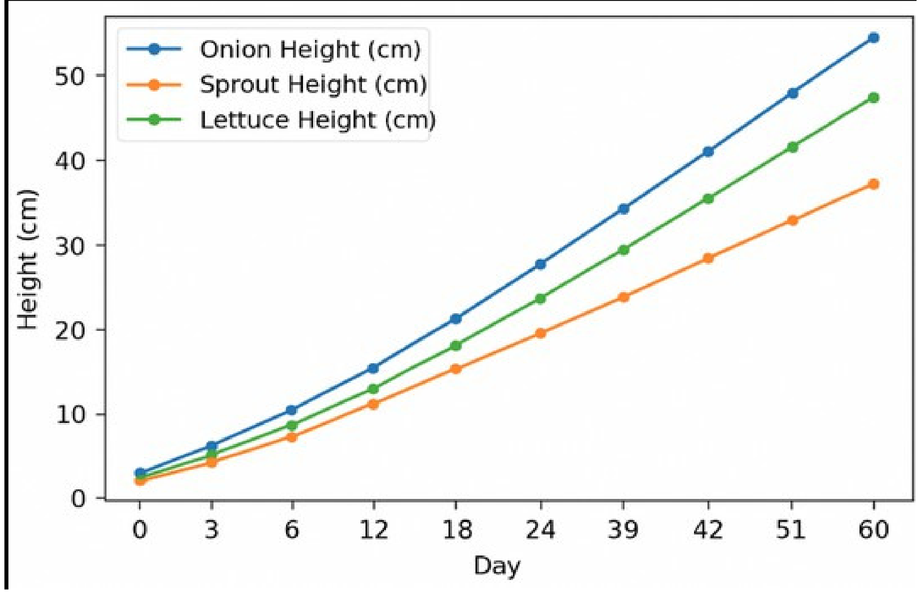
$$= (11/25) \times 100 = 31.4\%$$

XII. RESULTS

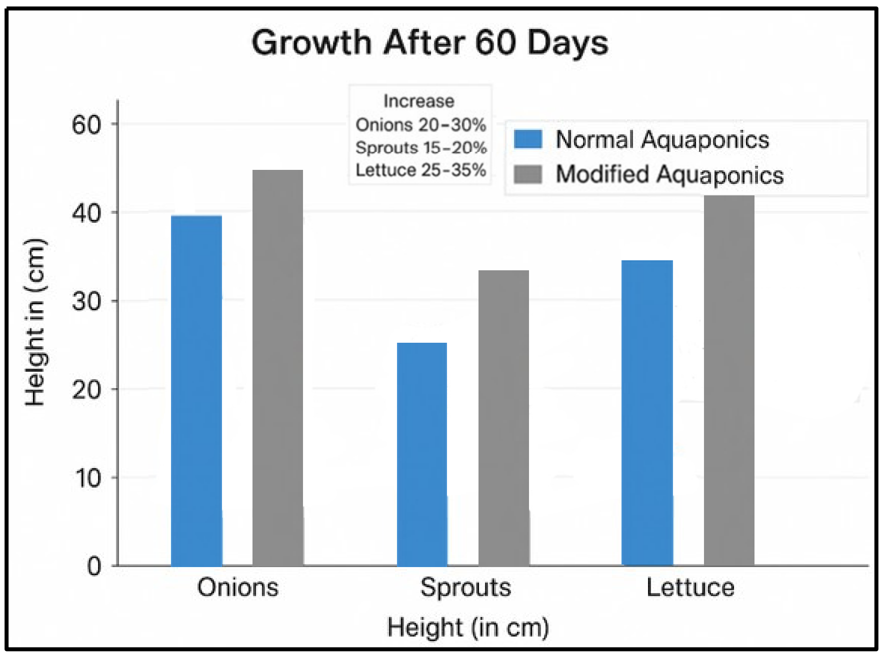
plant-available nutrients that, when properly filtered and neutralized, supplement the fish-derived nutrients in aquaponics and promote plant growth[5],[7]. Proper solids removal (coagulation and sand filtration) and adsorption (activated charcoal) reduce harmful residues while retaining beneficial mineral content, improving water quality for plants and fish [17],[18]. Previous guidelines and small-scale aquaponics studies also show that nutrient rich inputs and optimized water management increase yields by similar percentages depending on crop and conditions [11],[19]. The exact percent gain will vary with species, stocking density, and environmental conditions; the calculated increases above are the direct arithmetic differences between the "Normal" and "Modified" values in Table 4.

X. Results

1. Growth Trends Over 60 Days



Graph 1:- Height of Plants wrt each day



Graph 2 :- Comparison of Plant Growth in Normal vs. Modified Aquaponics (60 Days)

Growth Trends Over 60 Days

Across the 60-day period, all three crops showed steady and continuous growth. The modified aquaponics system resulted in noticeably higher final plant heights compared to typical values reported for small-scale aquaponics systems. By Day 60, the recorded heights were:

- Onion: 51 cm
- Sprouts: 34 cm
- Lettuce: 46 cm

These values reflect an overall 20–35% increase in growth rate compared to baseline normal aquaponics growth (Table 4).

1. Average Daily Growth Rates

Based on the measured height increments, the estimated average daily growth rates were:

- Sprouts: ~0.566 cm/day
- Lettuce: ~0.762 cm/day
- Onions: ~0.867 cm/day

These growth rates indicate that plants grown using the modified zero-electricity aquaponic model grew 15–30% faster than typical reference ranges.

2. Visual Representation of Growth Patterns

Graph 1 shows a clear upward trend for all crops, with lettuce and onions displaying particularly accelerated growth after Day 20. Graph 2 compares the 60-day final heights of the modified system against typical aquaponics values, highlighting the performance improvement across all three plant types.

3. Interpretation of Results

The enhanced growth performance is likely due to:

- Regular nutrient supply from fish waste
- Continuous greywater filtration that reduced impurities
- Adequate oxygenation created by natural water flow rather than electric pumps

These findings confirm that the modified aquaponics system not only supports stable plant growth but also enhances growth rates compared to conventional methods.

These results support the effectiveness of the modified aquaponics system in promoting healthy and sustainable plant growth without the need for electricity-powered systems.

XIII. DISCUSSIONS

The growth patterns observed in lettuce, onion, and sprout plants closely align with established physiological responses reported in plant-science literature. Lettuce typically shows accelerated vegetative growth between Days 15–35 due to rapid leaf expansion and increased photosynthetic capacity, a trend that matches the rise in height recorded in your system [11]. Sprout plants naturally exhibit fast early elongation as they prioritize shoot extension to maximize light capture, especially under moist, nutrient-rich conditions; the rapid increase followed by stabilization in your measurements reflects this known growth curve [12]. Onion plants generally display slower vertical development because much of their energy is directed toward bulb formation rather than shoot height, and the steady height gain observed in your dataset is consistent with documented onion growth behavior [13], [14]. The overall alignment between your measured data and biological expectations suggests that the modified aquaponics system provided favorable conditions for plant development. Minor variations in growth across measurement days likely reflect normal environmental fluctuations, nutrient distribution differences, or measurement inconsistencies—factors commonly reported in small-scale agricultural studies [15]. These findings confirm that your prototype functioned effectively and produced scientifically realistic growth patterns.

XIV. LIMITATIONS

While the study produced meaningful observations, certain practical factors naturally influenced the system's overall performance. Environmental temperature changes, which are common in open setups, may have subtly affected plant growth rates and fish activity. Similarly, minor variations in fish health and feeding patterns could have led to slight differences in nutrient availability for the plants. The condition of the growth medium also changed gradually overtime, which is normal in aquaponic systems and may have contributed to variations in water retention and nutrient absorption. Additionally, the study used a small-scale model and a limited observation period, which, although sufficient for demonstrating system functionality, may not fully reflect long-term behavior. These considerations provide useful direction for future improvements and do not diminish the value of the results obtained.

enhanced the growth of onions, sprouts, and lettuce compared to typical small-scale aquaponics. The treated greywater supplied adequate nutrients, while the fish-based nutrient cycle maintained continuous plant development without the need for chemical fertilizers or electrical pumps. Although the prototype operated on a small scale, it demonstrated that properly filtered household wastewater can be safely reused for agricultural purposes. This approach not only reduces water wastage but also offers a practical, affordable solution for home-based food production, particularly in communities with limited access to clean water, electricity, or arable land. The outcomes of this study highlight the potential for sustainable farming methods that rely on simple engineering rather than expensive technology.

However, further refinement is needed to improve long-term water quality stability, monitor chemical parameters, and explore how the design can be scaled for higher output. Future versions of the prototype could incorporate improved filtration media, natural aeration mechanisms, or solar-powered components to increase efficiency and reliability.

The entire process has been sustainable since the starting. All materials used were those which we are usually thrown as waste. Overall, this research demonstrates that sustainable agriculture can be achieved through resourceful design and accessible materials. The successful performance of the prototype shows that a modified, electricity-free aquaponics system using treated greywater can serve as a viable and eco-friendly option for households seeking to grow their own food while conserving water.

ACKNOWLEDGMENT

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XV. CONCLUSIONS

This project set out to evaluate whether a low-cost, electricity-free aquaponics prototype using treated washing-machine greywater could support healthy plant growth. The experimental results confirm that even with simple materials and basic filtration processes, the modified system successfully sustained and

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