

SYNOPSIS

1. Project ID: NSF- SCH-2025-111

Project Title: Sustainable Utilization of Greywater for Terrace Gardening in Urban Areas

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2. Introduction

Wastewater from a 7.5 kg washing machine is typically known as greywater and can range from 50 to 150 litres per cycle, depending on the machine type. This water can be safely reused for specific purposes with proper precautions. Wastewater from a washing machine can be reused for tasks that do not require drinking-quality water. The easiest way to do this is with a "laundry-to-landscape" system.

The research will focus on the utilization of domestic greywater for terrace gardening in urban areas. Increasing water scarcity, urbanization, and the need for sustainable practices in food production highlight the urgency of alternative water resources. The study will address how filtered greywater can be reused effectively in rooftop gardening to conserve freshwater, reduce urban heat effects, and promote eco-friendly urban living.

The expected outcome of this research will provide guidelines for safe and sustainable greywater use in terrace gardening, with potential benefits for water management, food security, and urban environmental sustainability.

Selection of Problem and Background Information

Urban areas face acute freshwater shortages due to rising population, industrial demands, and over-extraction of groundwater. Terrace gardening is gaining popularity as a solution for food security and greening of urban spaces, but it requires regular water supply. Greywater—constituting about 50–70% of household wastewater—represents an underutilized resource that can replace fresh water for irrigation purposes if treated appropriately.

This research problem is significant because it provides a sustainable approach to water recycling while promoting urban agriculture. Societal impact includes reduced pressure on freshwater resources, improved urban greenery, cost savings for households, and contribution to sustainable cities in line with UN Sustainable Development Goal 11 (Sustainable Cities and Communities) and Goal 6 (Clean Water and Sanitation).

Objective

Research Problem:

Freshwater scarcity limits the feasibility of terrace gardening in urban areas, and greywater is an underutilized resource with potential risks and benefits.

Hypothesis

It is hypothesized that filtered greywater can be safely and effectively used for terrace gardening, and plant growth will not be significantly different from plants irrigated with freshwater. Additionally, greywater irrigation may improve soil nutrient availability due to organic residues, although excessive use may lead to mild salt accumulation.



Research Objectives:

1. To evaluate the feasibility of greywater for terrace gardening.
2. To assess plant growth response when irrigated with greywater compared to freshwater.
3. To analyze the impact of greywater irrigation on soil quality and plant health.
4. To design a low-cost greywater filtration system suitable for urban households.

3. Methodology & Procedure

Experimental Design:

1). Collection and Filtration of Greywater

- a. Greywater will be collected from laundry rinse water.
- b. A three-stage filtration system (gravel-sand-activated charcoal) will be constructed.



II). Experimental Setup

- a. Location: Terrace garden with uniform sunlight exposure.
- b. Plant species: Fenugreek (*Trigonella foenum-graecum*) will be selected.
- c. Pots: 2 L plastic grow bags with standardized soil mixture (soil:compost:sand = 2:1:1).
- d. Groups:
 - i. Control Group: Irrigated with freshwater.
 - ii. Experimental Group: Irrigated with filtered greywater.



III). Irrigation Schedule

- a. Plants will be watered with equal volumes (50 mL per pot, every day).

IV). Data Collection Parameters:

- a. Plant Growth: Height (cm) and leaf count.
- b. Water Quality Analysis: pH, turbidity, and TDS.

Variables:

- **Independent Variable:** Type of irrigation water (freshwater vs. greywater).
- **Dependent Variables:** Plant growth parameters (height, leaf number, yield), soil properties (pH, salinity), and water-use efficiency.
- **Controlled Variables:** Type of soil, plant species, container size, sunlight exposure, and volume of water applied.

Cause and Effect Study:

By varying the water source (independent variable), the study will measure changes in plant growth (dependent variables) while maintaining all other conditions constant.

Control:

Plants irrigated with freshwater will serve as the control group for comparison with plants irrigated using filtered greywater.



Irrigation



Seeding

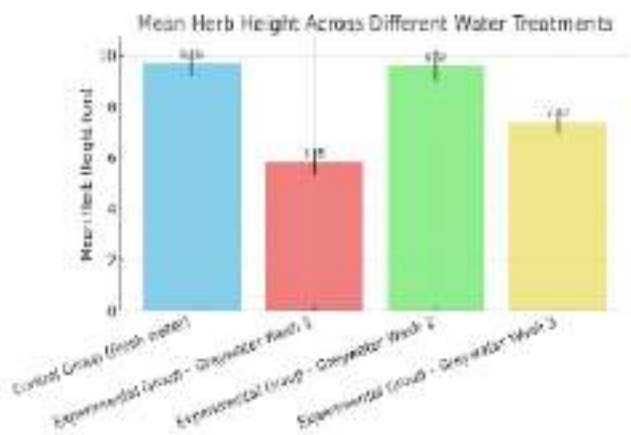


4 & 5: Results & Discussion:



Table 1: Plant Growth

Group	Herb Height (cm)													
	Herb number	1	2	3	4	5	6	7	8	9	10	11	12	13
Control Group (Fresh water)		9	10	9	10	10	10	10	10	9	9	10	10	10
Experimental Group - Greywater Wash 1		6	6	5	6	6	6.5	6	5	6	5	6	6	6.5
Experimental Group - Greywater Wash 2		9	9	9.5	10	9	10	10.5	10.5	9	10	10	9	9.5
Experimental Group - Greywater Wash 3		7.5	7	6.5	7	7.5	7.5	8	7.5	8	7	8	8	7

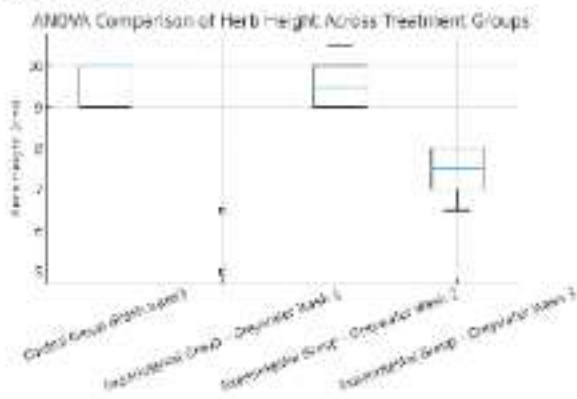


Control Group (Fresh Water): tallest growth

Greywater Wash 1: lowest growth

Greywater Wash 2: comparable to control

Greywater Wash 3: moderate recovery



ANOVA Results:

- F-statistic: 166.28

- p-value: 2.35×10^{-07}

Interpretation:

Since the p-value is much less than 0.05, there is a statistically significant difference in herb height among the four groups.

Discussion:

- The Control Group (Fresh Water) and Greywater Wash 2 groups show higher mean herb heights, indicating better growth performance (Table 1).
- The Greywater Wash 1 group shows the lowest herb height, suggesting possible inhibitory effects of the first wash greywater on plant growth.
- Greywater Wash 3 shows moderate growth, indicating partial tolerance or improved water quality after multiple washes.

The ANOVA test confirms that water quality significantly influences herb height. Reusing greywater may be feasible only after adequate treatment or dilution, as untreated wash water (first wash) negatively impacts plant growth compared to fresh water.

Table 2: Plant Growth Parameters

Group	Plant Height (cm, Mean ± SD)	Leaf Count	Days to 50 % Germination	Fresh Leaf Yield (g)
Control Group (Fresh Water)	9.69 ± 0.48	2	4	6
Experimental Group – Greywater Wash 1	5.96 ± 0.48	2	7	9
Experimental Group – Greywater Wash 2	9.72 ± 0.52	2	5	7
Experimental Group – Greywater Wash 3	7.42 ± 0.45	2	5	7

Results:

Statistical analysis of herb (plant) height using one-way ANOVA showed a significant variation among treatments ($F = 166.28, p < 0.001$).

The Control Group (Fresh Water) and Greywater Wash 2 exhibited the highest mean plant heights (≈ 9.7 cm), while Greywater Wash 1 showed the lowest mean height (≈ 5.96 cm).

Standard deviations ranged from 0.45 to 0.52 cm, indicating consistent growth patterns within each treatment (Table 2).

In terms of other growth parameters:

- Leaf count remained similar (2 leaves) across all treatments, suggesting minimal effect of water source on early leaf initiation.
- Days to 50 % germination increased under greywater use, with Greywater Wash 1 showing the slowest germination (7 days) compared with the control (4 days).
- Fresh leaf yield was highest in Greywater Wash 1 (9 g), possibly due to higher moisture retention or residual nutrients, though this did not correspond with increased plant height.

Discussion

The results demonstrate that water quality strongly influences plant height and early growth characteristics.

- Plants irrigated with fresh water and Greywater Wash 2 performed best, indicating favorable growing conditions and nutrient balance (Table 2).
- The first wash greywater (Wash 1) negatively affected height and delayed germination, suggesting that detergent residues or high salinity inhibited early development.
- Greywater Wash 3 showed intermediate performance, implying that multiple washes or partial dilution reduced harmful substances, improving its suitability for irrigation.

Overall, the data confirm that greywater reuse can be feasible if adequately treated or diluted. The combination of ANOVA results and observed growth trends underscores the importance of water-quality management for sustainable plant cultivation.

Physico-Chemical Properties of Water Samples



Table 3: Physico-Chemical Properties of Water Samples

Group	pH	Total Dissolved Solids (mg/L)	Odour	Colour
Control Group (Fresh Water)	7.2	451	Odourless	Clear
Experimental Group – Greywater Wash 1	8.1	534	Surf smell	Bluish turbid
Experimental Group – Greywater Wash 2	7.4	445	Odourless	Clear
Experimental Group – Greywater Wash 3	7.3	451	Odourless	Clear

Results

The pH and total dissolved solids (TDS) varied slightly across the water samples. The Control Group (Fresh Water) recorded a neutral pH of 7.2 and a TDS of 451 mg/L, which are within acceptable limits for irrigation.

The Greywater Wash 1 sample showed a higher pH (8.1) and elevated TDS (534 mg/L), along with a noticeable surf odour and bluish turbidity, indicating the presence of detergent residues.

In contrast, Greywater Wash 2 and Greywater Wash 3 exhibited near-neutral pH (7.3–7.4) and clear appearance, comparable to the control sample, reflecting improvement in quality with repeated washing or dilution.

Discussion

The observed results suggest that the first wash greywater contained higher concentrations of surfactants and dissolved solids, contributing to alkaline pH and turbidity. These factors can adversely affect plant growth by altering soil structure and nutrient absorption.

However, the second and third wash samples showed reduced TDS and neutral pH, indicating that subsequent greywater cycles become progressively cleaner and more suitable for reuse in irrigation.

The clear odour and colour of Greywater Wash 2 and Wash 3 also support this conclusion, implying that simple filtration or dilution may further enhance their usability.

Collectively, the water quality results align with the plant growth performance, where Greywater Wash 2 produced growth comparable to the fresh water control, while Greywater Wash 1 inhibited growth due to poorer water quality.

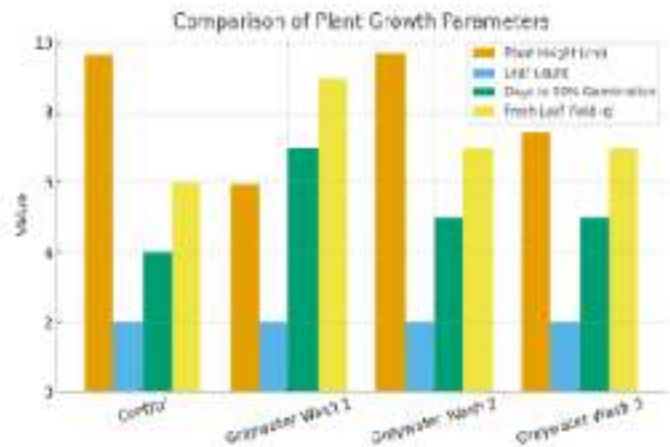


Figure 1. Comparative plant growth parameters under different water treatments.

Discussion of Figure 1: Comparison of Plant Growth Parameters

The bar chart illustrates the variation in plant height, leaf count, days to 50% germination, and fresh leaf yield across the four treatments—Control (Fresh Water) and Greywater Washes 1, 2, and 3.

1. Plant Height (cm):

Plant height was highest in the Control and Greywater Wash 2 groups (≈ 9.7 cm), indicating optimal growth under fresh water and second-wash greywater conditions. The Greywater Wash 1 treatment recorded the lowest height (≈ 5 cm), showing that first-wash greywater, which contains the highest detergent residue, inhibits vertical growth. Greywater Wash 3 (≈ 7.5 cm) showed moderate recovery, reflecting improved water quality through repeated washing.

2. Leaf Count:

Leaf count remained constant (2 leaves) across all treatments, suggesting that water quality did not significantly affect early leaf initiation or morphogenesis.

3. Days to 50% Germination:

Germination was fastest under the Control treatment (4 days), while Greywater Wash 1 took the longest (7 days), indicating stress due to detergent residues and higher TDS. Greywater Washes 2 and 3 reached 50% germination in about 5 days, similar to the control, confirming reduced stress levels with improved greywater quality.

4. Fresh Leaf Yield (g):

Yield was highest in Greywater Wash 1 (9 g), likely due to higher moisture retention or organic residue accumulation, even though plant height was low. The Control, Wash 2, and Wash 3 groups produced moderate yields (6–7 g), balancing vegetative and physiological growth.

Overall Interpretation:

The figure clearly demonstrates that water quality significantly influences plant growth performance. While first-wash greywater impairs growth due to chemical stress, subsequent washes (Wash 2 and Wash 3) provide nearly equivalent results to freshwater. These outcomes highlight that reused or filtered greywater can be a sustainable irrigation source for terrace gardening when managed properly.

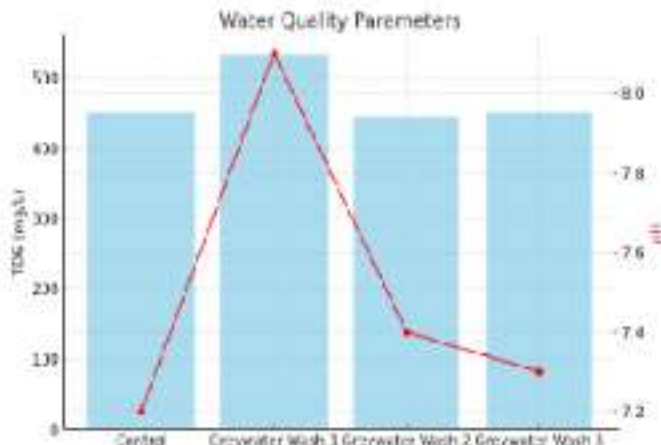


Figure 2. Comparison of water quality parameters (TDS and pH) among treatment groups.

Discussion of Figure 2: Water Quality Parameters

The figure presents the Total Dissolved Solids (TDS) and pH values of water samples collected from the control and three greywater treatments.

1. Total Dissolved Solids (TDS):

The Control (Fresh Water) sample recorded a TDS of approximately 450 mg/L, which is well within the acceptable range for irrigation.

In contrast, Greywater Wash 1 showed the highest TDS (~534 mg/L), indicating a higher concentration of dissolved salts, surfactants, and detergent residues. Such elevated TDS levels can increase soil salinity and adversely affect plant nutrient uptake.

Greywater Wash 2 and 3 exhibited lower TDS values (~445-451 mg/L), comparable to the control, suggesting that with each successive wash, water quality improved due to dilution and reduced detergent content.

2. pH:

The pH trend followed a similar pattern. Fresh water had a neutral pH (7.2), while Greywater Wash 1 was slightly alkaline (pH 8.1) due to soap residues. Greywater Wash 2 (pH 7.4) and Wash 3 (pH 7.3) approached neutrality again, confirming that detergent impact diminishes in subsequent wash cycles.

3. Interpretation:

The graph clearly demonstrates that Greywater Wash 1 exhibits the poorest quality, with both elevated TDS and alkaline pH. However, Greywater Wash 2 and 3 show considerable improvement, aligning closely with the control sample.

These observations confirm that repeated washing or pre-filtration effectively reduces chemical load and restores water quality, making later greywater cycles suitable for reuse in non-potable applications like terrace gardening.

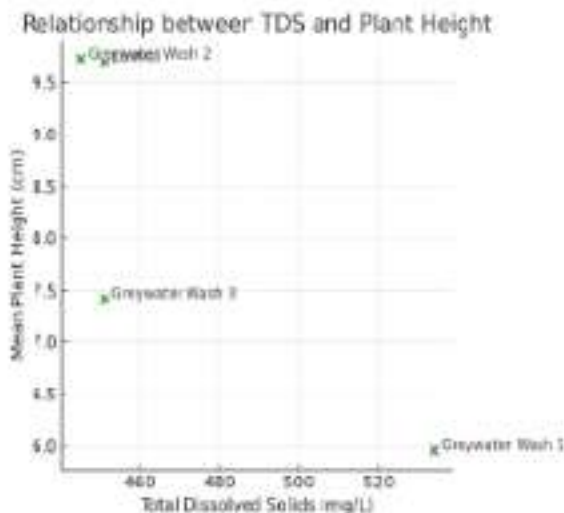


Figure 3. Correlation between Total Dissolved Solids and Mean Plant Height.

Discussion of Figure 3: Relationship between TDS and Plant Height

The scatter plot illustrates the relationship between Total Dissolved Solids (TDS) in irrigation water and the mean plant height observed across the four treatments.

1. Trend Analysis:

An inverse relationship is observed — as TDS increases, plant height decreases.

Control (Fresh Water) and Greywater Wash 2, which had lower TDS values (~445–451 mg/L), showed the greatest mean plant heights (~9.7 cm).

Greywater Wash 1, with the highest TDS (534 mg/L), recorded the lowest height (~5.96 cm), indicating that elevated dissolved salts and detergent residues in the first wash water adversely affect plant growth.

Greywater Wash 3 (TDS \approx 451 mg/L) demonstrated intermediate growth (\approx 7.4 cm), suggesting partial improvement in water quality and plant performance.

2. Interpretation:

The data support the conclusion that excessive dissolved solids—likely from detergents and surfactants—reduce plant water uptake and alter soil osmotic balance, thereby inhibiting growth.

In contrast, moderate TDS levels, as in Wash 2 and the control, maintain favorable conditions for plant metabolism and height development.

3. Implications:

This relationship emphasizes the importance of monitoring and managing greywater quality before reuse. Effective filtration or dilution lowers TDS to safe levels, allowing sustainable use of greywater for irrigation without compromising plant health.

6. Conclusion:

The present experiment conclusively demonstrates that water quality exerts a profound influence on herb growth and development. Plants irrigated with fresh water exhibited the most favorable growth performance, while those treated with greywater showed varied responses depending on the level of contamination and treatment of the water.

The results clearly indicate that greywater reuse can be a viable practice for terrace gardening, provided that the water undergoes adequate filtration, dilution, or natural settling to remove harmful residues. The first wash greywater, which contained the highest concentration of detergent and surfactant residues, proved unsuitable for direct irrigation due to its alkaline pH and elevated total dissolved solids (TDS). Such chemical loads are detrimental to plant growth as they hinder nutrient uptake and affect soil structure.

Conversely, the second and third wash greywater samples showed substantial improvement in water quality, characterized by near-neutral pH, reduced TDS levels, and the absence of odour or turbidity. Plants irrigated with these later greywater samples displayed growth parameters comparable to the control group, signifying that the harmful effects of detergent residues were minimized through repeated washing or dilution.

These findings establish that treated or partially recycled greywater can effectively supplement freshwater sources in small-scale urban agriculture, particularly terrace and kitchen gardening systems. Adopting such greywater management practices contributes to urban water conservation, reduces household freshwater demand, and minimizes wastewater discharge into municipal systems.

Overall, the study highlights a sustainable, low-cost, and eco-friendly approach to utilizing domestic wastewater in horticultural applications. This aligns with the United Nations Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities), by promoting responsible water use and encouraging green urban living.

7. References

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