Evaluation of Greywater Irrigation Impact on Soil and Edible Crops

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Abstract. Agriculture, a cornerstone of human sustenance, is facing unprecedented challenges in meeting the escalating global food demand. The world's population is projected to reach 9.7 billion by 2050, putting immense pressure on the agricultural sector to increase food production (FAO, 2017). Irrigation, a crucial component of modern agriculture, plays a vital role in ensuring crop yields, and its importance cannot be overstated. However, the increasing demand for freshwater resources has led to a significant depreciation in available freshwater resources, threatening the very foundation of global food security. This study investigates the potential of greywater utilization for irrigation as an alternative to fresh water, focusing on its effects on soil and crop performance. To examine the impact of greywater irrigation on soil and crop health, three crops i.e., coriander, spinach, and lettuce are considered. Conducted in Muzaffargarh City, characterized by predominantly hot weather with occasional cloudiness, the efficacy of greywater irrigation is explored as compared to tap water as control for comparison. There employed a controlled setup using no. of pots per crop type. The greywater applied is of 100%, 75%, 50%, 25% and 0% concentration. Greywater samples are collected from kitchen regularly for application. The various water quality tests, including electrical conductivity, calcium, magnesium, sodium, carbonate, bicarbonate, chloride, residual sodium carbonate, and sodium adsorption ratio are performed. Soil and crop samples are analyzed for total dissolved sodium, soil pH, organic matter content, available phosphorus, available potassium, soil saturation, and texture. Results indicate that greywater exhibits higher electrical conductivity and concentrations of calcium, magnesium, sodium, carbonate, bicarbonate, and chloride compared to tap water. However, greywater also contains residual sodium carbonate and demonstrates a higher sodium adsorption ratio. Soil analysis reveals an increase in total dissolved sodium levels post-irrigation with greywater, along with a decrease in soil pH. Moreover, greywater irrigation leads to an improvement in soil organic matter content. This study's findings will contribute to sustainable water management strategies, minimizing freshwater usage and preserving this valuable resource for other purposes.

Keywords: Greywater, Irrigation, Soil Health, Crop Growth, Water Quality.

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1. Introduction

The global water crisis is adversely intensifying the rate of freshwater depletion, with an estimated 40% of the world's population facing water scarcity (WWAP, 2018). The agricultural sector, withdrawing fresh water source accounting to 70% globally, is a significant contributor to this crisis (FAO, 2017). To address this reduction in fresh water resources, various approaches have been employed, including efficient irrigation systems, water conservation and storm water harvesting. Despite these efforts, the gap between freshwater supply and demand continues to enlarge, demanding innovative solutions to ensure sustainable food and agriculture security. Various management practices have been implemented to address water scarcity in crop production, including drip water irrigation, deficit irrigation, organic amendments, organic mulching, and the use of seawater for irrigation (Badr and Taalab, 2007; Kazemeini et al., 2009; Saeed and Ahmad, 2009; Saeed et al., 2014).

The use of greywater for small-scale irrigation of food crops has gained attention as a potential solution to above said problem as well as greywater disposal problem in the areas with limited sanitation services. Greywater, which refers to untreated household wastewater excluding toilet waste, presents an opportunity to contribute to household food supply and informal income generation.

In this context, alternative water sources, such as greywater, have gained attention as a potential solution. By focussing on the water demand for increasing population greywater, which contained nutrients like nitrogen phosphorous and potassium, may be considered as a readily available and valuable resource for crop production. Greywater can be broadly classified into two categories: greywater and dark greywater. Greywater, with its relatively low contaminant levels, offers a promising alternative for irrigation purposes. The composition of greywater varies depending on factors such as household size, water usage patterns, and wastewater management practices etc.

This study aims to investigate the potential of greywater utilization for irrigation, focusing on its effects on soil and crop performance, and freshwater conservation. By exploring the viability of greywater irrigation, it can contribute to the development of sustainable water management strategies, helping to address the pressing issue of freshwater depletion and global food security. The findings of this study will provide valuable insights into the potential of greywater irrigation, practice in the agricultural sector.

2. Literature Review

United Nation of Environment Program concluded that Grey water refers to the wastewater collected from laundry, baths, showers, kitchens, and hand wash basins. Unlike black water, in which waste from toilets is also incorporated, grey water does not contain significant levels of pathogens, making it an attractive source for non-potable water utilization. In the context of water demand for agriculture, grey water can be a valuable resource for irrigation, contributing to water conservation and sustainable farming practices (UNEP, 2011).

Due to lesser resources of fresh water, greywater has gained attention as a potential water resource for irrigation purposes. Greywater contains compounds such as surfactants, soaps, oils, boron, and salts, which can influence soil and plant characteristics (Travis et al., 2008; Wiel-Shafran et al., 2006).

2.1 Greywater Composition and its Impact on Plants and Soil

Greywater production varies depending on water availability, with estimates ranging from 180-300 liters per capita per day in households with multiple taps inside the house, to 9-50 liters per person per day in households located at a far distance from a standpipe (Alcock, 2002). As the volume of greywater per capita decreases, the concentration of pollutants in it increases. Pollutant loads in greywater conserved in open spaced settlements in South Africa were found to be higher than those from developed countries where sufficient amount of water is delivered for capita per day (Carden et al., 2007; Roesner et al., 2006). Significantly, the presence of alkalinity, calcium (Ca), chloride (Cl), boron (B), potassium (K), sodium (Na), total coliforms, and E. coli in greywater were identified as significant pollutants (Rodda et al., 2010).

When considering the effects of greywater irrigation on plants and soil, the concentrations of plant macronutrients particularly nitrogen, phosphorus and sodium are of particular interest. While plant nutrients can enhance plant growth, Na can be toxic to plants, causing salinization of the soil and compromising its ability to support plant growth (DWAF, 1996; Morel and Diener, 2006). Therefore, it is crucial to monitor the sodium adsorption ratio (SAR) and the concentrations of Ca+Mg ions, as they play crucial role in tackling the adverse effects of sodium salinity.

2.2 Implications for Soil, Crop Growth, and Human Health

Disquiets have been raised regarding the adverse effects of surfactants, oils and grease on greywater-irrigated soil. These contaminants can have detrimental impacts on the structure & healt of soil. Also the potential health risks associated with greywater irrigation are primarily related to the presence of pathogens, which may be found in greywater, collected from bathing, laundry, and kitchen activities (Gross et al., 2005; Travis et al., 2008; Wiel-Shafran et al., 2006).

2.3 Implications for Agricultural Sustainability in Pakistan

Gleick concluded that the shortage of fresh water and the increasing salinity of agricultural land are major global challenges in delivering sufficient food productivity for the enlarging population. Earth surface’s 70% is covered with water, only 3% of it is fresh water, while the rest of it is saline. Moreover, a significant portion of this fresh water is entangled in ice caps and glaciers, leaving a limited supply of fresh water for human beings, particularly in agriculture. Around 70% of the accessible fresh water is utilized for agricultural sector, while individuals require minimum of 120 litres of water per capita per day for domestic use (Gleick, 1993).

Pakistan, classified as a semi-arid to arid country, faces low rainfall and is heavily dependent on irrigation for crop production. With climate change leading to higher temperatures, rising sea levels, melting glaciers, increased flooding, and more frequent droughts, Pakistan's crop yields and food production are adversely affected. The country has approximately 22 million hectares of cultivated land, of which 85% is irrigated and the remaining 3 million hectares depend on rainfall. However, the annual rainfall varies between 100 mm to 700 mm, and droughts further exacerbate the challenges faced by the agricultural sector. Drought-related yield reductions of up to 17% have been reported, and globally, around 45% of agricultural lands regularly experience drought, making it difficult to meet the increasing food demands of the world's population (Ashraf and Foolad, 2006; Bot et al., 2000; FAO, 2014).

3. Methodology

3.1 site selection & its characteristics

The site selected for the study is located in city Muzaffargarh, Pakistan as this is a major city which has total area of about 600000 acre out of which 225000 acre on average is utilized for cultivation of different crops including the vegetables of onions, carrots, turnips, potatoes, cauliflower, peas, tomatoes, garlic and chilies, the fruits of Mangoes, dates, pomegranates, falsa, Jamun, pears & bananas and the major crops includes Wheat, sugarcane, cotton, rice, jawar, mungi beans, masoor, maize, mustard seeds and sunflower seeds etc. The location of selected site is shown in figure. 1. Here at selected site, normal environmental conditions were maintained, with minute variations in natural light and temperature. As far the weather condition is concerned, it was characterized by hot conditions with occasional cloudy days, reflecting the typical climate of the selected areas. These conditions influenced the growth and water needs of the plants.

3.2 Selection of Crops

For this study, coriander, spinach and lettuce crops are selected as a no. of times in literature it is discussed that only the leafy crops are suitable for waste water or greywater irrigation. Some of salient characteristics are discussed in the table. 1

Figure 1: Location of Experiment Setup

Table 1: Salient features of crops

CORIANDER	SPINACH	LETTUCE
High Water Requirement: Coriander has moderate to high water needs, making it an ideal candidate for assessing the impact of greywater on water-intensive crops. This characteristic helps evaluate if greywater can meet the hydration demands of such plants without compromising their growth.	**Rapid Growth:** Spinach grows quickly, allowing for the timely assessment of greywater effects on plant development. Rapid growth cycles are beneficial for observing immediate impacts and making timely adjustments to the study.	**Sensitivity to Water Quality:** Lettuce is known for its sensitivity to water quality and contaminants. This makes it a suitable crop for testing the safety and effectiveness of greywater irrigation, as any adverse effects are likely to be evident.
Nutrient Sensitivity: Coriander is sensitive to nutrient levels in the soil, particularly nitrogen, phosphorus, and potassium. Using coriander allows the study to monitor how greywater, which can have varying nutrient levels, affects nutrient-sensitive crops.	**Leafy Green Characteristics:** As a leafy green, spinach is highly sensitive to the quality of irrigation water. This makes it an excellent indicator of any negative effects of greywater, such as potential contamination or nutrient imbalance.	**Fast Maturity:** Similar to spinach, lettuce matures quickly, providing a swift evaluation period for the study. This fast growth rate is advantageous for observing the short-term effects of greywater on plant health and development.

Short Growth Cycle: Coriander has a relatively short growth cycle, which enables the observation of greywater effects on crop development and yield within a manageable timeframe. This characteristic makes it easier to conduct multiple iterations of the experiment if needed.	**High Nutrient Demand:** Spinach requires a rich supply of nutrients, particularly nitrogen. This characteristic helps evaluate whether greywater, often containing residual nutrients from household use, can adequately support nutrient-demanding crops.	**Common Edible Crop:** Lettuce is widely consumed and grown, making the findings of the study relevant and applicable to a broad range of agricultural practices. Understanding how greywater affects a common edible crop can have significant implications for food safety and sustainability.

3.3 Field Setup

Total of five patches are made, each of which consists of Six pots to be used for irrigation purpose. In each patch, one crop has two specimen of pots i.e. 2 pots for spinach, 2 for lettuce and 2 for coriander. Out of five patches, one patch is utilized for tap water irrigation as a control and other four patches are used for greywater irrigation application having greywater concentrations of 100%, 75%, 50%, and 25% respectively. Also these pots are placed in a yard. The reflection of a patch of six pots placed in house lawn is reflected in figure. 2.

Figure 2: Patch of pots

3.4 Water Sampling & Testing Parameters:

The Greywater is collected from kitchen wash basin or sink at an interval of five days. This collected greywater is stored in Polyethylene Terephthalate (PET) water bottles of 300ml in refrigerator at a temperature as low as 4-8 degree in celsius and used for daily irrigation in respective pots. It is ensured that the collected greywater samples represents the typical household wastewater. To access the effect of greywater at different ratios, five concentrations with 0%, 100%, 75%, 50% & 25% concentrated greywater are executed in this study. The collected greywater and the PET bottles used for storing it are shown in figures. 3 & 4.

During the execution of scheme of research, water samples are collected in the same type of PET bottles and sent to the laboratory for testing. The testing parameters includes Electrical Conductivity (EC), (Ca+Mg), Sodium (Na), Carbonate (CO3), Bi-carbonate (HCO3), chloride (Cl), residual sodium carbonate (RSC) and SAR.

3.5 Soil Sampling & Testing Parameters

For soil analysis, soil samples are collected by composite sampling technique in which the sample of soil is produced by mixing the soil from different pots of same crop. The soil parameters are analysed before sowing the seeds of respective crops and also after the harvesting of selected crops. This helped in assessing the impact of greywater on soil properties. The collected samples are immediately taken into the soil testing laboratory for testing of parameters of total dissolved sodium, soil pH, organic matter contents, available phosphorous, available potassium, saturation level and the texture of soil being used for irrigation of selected crops. Total five batches with each batch consists of 6 pots, two for each crop are made. These batches are irrigated with 0%, 100%, 75%, 50% & 25% concentrated greywater. After harvesting, the composite samples of soil are gathered by mixing the soil samples from both pots of same crop receiving one greywater concentration. The details of 5 batches receiving different concentrations of greywater are shown in table 2. The collected soil samples for testing before sowing of seeds and after harvesting of crops are shown in figures. 5(a) & 5(b) respectively. For physical analysis of harvested crops, only the colour appearance of leaves, length of root and shoot length of stem are observed for the crops receiving greywater with various concentration as mentioned before.

Figure 3: Collected wastewater

Figure 4: PET bottles for storage

Figure 5(a): Soil sample before sowing

Figure 5(b): soil sample after harvesting of crop

Table 2: Field setup of crop pots for various concentrations of greywater irrigation.

Mix	No. of Pots	Type of Crop Irrigated Greywater Percentage
C_0	2	Coriander irrigated with 0% concentrated greywater.
C_{100}	2	Coriander irrigated with 100% concentrated greywater.
C_{75}	2	Coriander irrigated with 75% concentrated greywater.
C_{50}	2	Coriander irrigated with 50% concentrated greywater.
C_{25}	2	Coriander irrigated with 25% concentrated greywater.
L_0	2	Lettuce irrigated with 0% concentrated greywater.
L_{100}	2	Lettuce irrigated with 100% concentrated greywater.
L_{75}	2	Lettuce irrigated with 75% concentrated greywater.
L_{50}	2	Lettuce irrigated with 50% concentrated greywater.
L_{25}	2	Lettuce irrigated with 25% concentrated greywater.
S_0	2	Spinach irrigated with 0% concentrated greywater.
S_{100}	2	Spinach irrigated with 100% concentrated greywater.
S_{75}	2	Spinach irrigated with 75% concentrated greywater.
S_{50}	2	Spinach irrigated with 50% concentrated greywater.
S_{25}	2	Spinach irrigated with 25% concentrated greywater.

4. Results and Discussion

4.1 Dominant Weather Conditions

The weather conditions exhibited significant temperature fluctuations and varying weather patterns at starting days. Morning temperatures ranged from 22°C to 38°C, with a noticeable rise in temperature towards the end of the study, potentially stressing the plants. Afternoons consistently recorded the highest temperatures, peaking at 34°C as an indicative of the typical hot climate conditions. Evenings were initially cooler at 15°C, but temperature raised up to 35°C. Clear skies were predominant, dispersed with partly cloudiness, and occasional breezes were blown. As the temperature is a crucial factor for irrigation water requirement of a crop so the variation in temperature and dominant weather conditions are recorded on regular interval. The table. 3 highlights periods of potential plant stress due to high temperatures on coriander, spinach, and lettuce under these varying conditions.

4.1 Water Quality Analysis

The water results analysis table. 4 and figure. 6 demonstrates a comparative study of greywater at varying concentrations and its potential effects when diluted with tap water. The findings of tests is shown in table. 4. The EC values for greywater decrease progressively from 2107 µS/cm at 100% concentration to 1537 µS/cm at 25% concentration, compared to tap water's 1273 µS/cm. This suggests that dilution significantly reduces the ion concentration, making diluted greywater more comparable to tap water and potentially lessening the risk of soil salinity. Similarly, level of Ca & Mg ions dropped from 8.28 Meq/L in undiluted greywater to 5.56 Meq/L at 25% concentrated greywater, while a value of 4.1 Meq/L found is found in tap water, indicating a beneficial reduction in hardness.

The level of Na ions in greywater also decrease with dilution, from 12.79 Meq/L at 100% concentration to 9.07 Meq/L at 25% concentration, compared to 8.63 Meq/L in tap water. This reduction in Na concentration with dilution is crucial for minimizing potential soil structure issues and avoiding sodium toxicity in plants. HCO3 levels follow a same trend with greywater values reducing from 7.1 Meq/L to 6.12 Meq/L and 5.84 Meq/L in tap water, which helps in maintaining soil pH stability. Amount of Cl ions remained relatively constant across all greywater samples and are comparable to tap water, suggesting minimal risk from chloride toxicity.

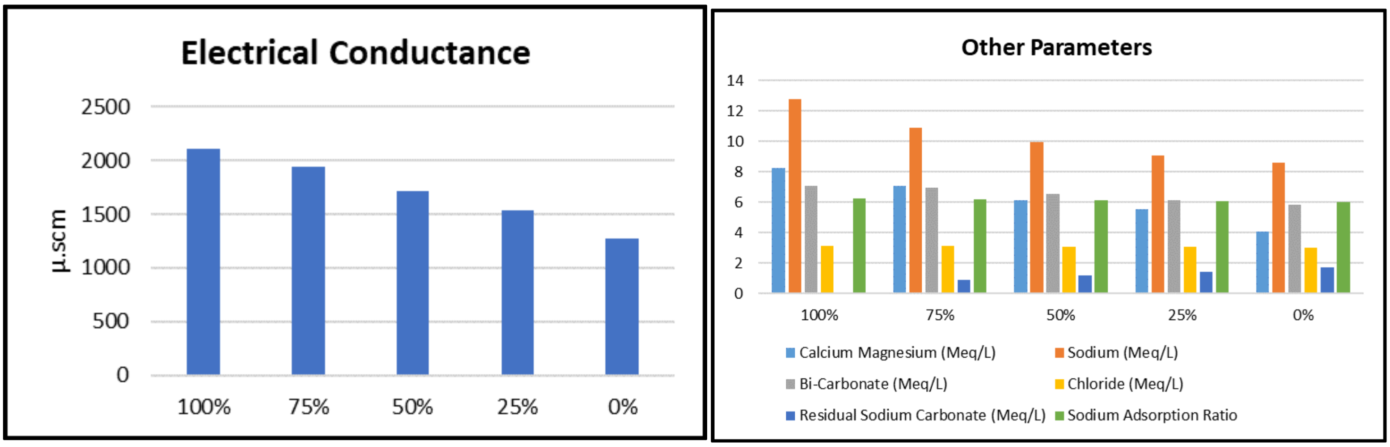
The values of RSC in greywater exhibits an interesting trend, starting at zero in undiluted samples and increasing with dilution, peaking at 1.43 Meq/L in the 25% concentration and dropping to 1.74 Meq/L in 0% greywater mix. This indicates that moderate dilution can manage alkalinity issues more effectively. The SAR in greywater ranges from 6.28 at full concentration to 6.09 at 25% concentration while in tap water it is at 6.03. This slight reduction with dilution suggests that while greywater has a higher SAR, careful dilution can bring it closer to the safer levels observed in tap water, potentially mitigating adverse effects on soil permeability and structure.

Table 3: Dominant weather conditions during execution of research

Day	Date	Time	Temperature (°C)	Weather Condition
Day 01	2024-04-20	Evening	15	Clear Skies
Day 02	2024-04-21	Evening	20	Partly Cloudy
Day 03	2024-04-22	Morning	25	Sunny
Day 04	2024-04-23	Afternoon	30	Hot and Sunny
Day 05	2024-04-24	Evening	28	Clear Skies
Day 06	2024-04-25	Morning	22	Partly Cloudy
Day 07	2024-04-26	Afternoon	32	Hot and Sunny
Day 08	2024-04-27	Evening	27	Clear Skies with a Slight Breeze
Day 09	2024-04-28	Morning	23	Partly Cloudy
Day 10	2024-04-29	Afternoon	33	Hot and Sunny
Day 11	2024-04-30	Evening	29	Clear Skies
Day 12	2024-05-01	Morning	24	Partly Cloudy
Day 13	2024-05-02	Afternoon	32	Hot and Sunny
Day 14	2024-05-03	Evening	28	Clear Skies
Day 15	2024-05-04	Morning	25	Partly Cloudy
Day 16	2024-05-05	Afternoon	30	Hot and Sunny
Day 17	2024-05-06	Evening	29	Clear Skies
Day 18	2024-05-07	Morning	26	Partly Cloudy
Day 19	2024-05-08	Afternoon	31	Hot and Sunny
Day 20	2024-05-09	Evening	30	Clear Skies
Day 21	2024-05-10	Morning	27	Partly Cloudy
Day 22	2024-05-11	Afternoon	32	Hot and Sunny
Day 23	2024-05-12	Evening	28	Clear Skies
Day 24	2024-05-13	Morning	25	Partly Cloudy
Day 25	2024-05-14	Afternoon	29	Hot and Sunny
Day 26	2024-05-15	Evening	32	Sunny
Day 27	2024-05-16	Morning	34	Sunny
Day 28	2024-05-17	Afternoon	34	Sunny
Day 29	2024-05-18	Evening	35	Sunny
Day 30	2024-05-19	Morning	38	Sunny

Table 4: Water Quality Analysis

Tests	Formulas	Units	Greywater Percentage				
			100 %	75 %	50%	25%	0%
Electrical Conductivity	σ	µ.scm	2107	1945	1721	1537	1273
Calcium Magnesium	Ca+Mg	Meq/L	8.28	7.08	6.12	5.56	4.1
Sodium	Na	Meq/L	12.79	10.88	9.98	9.07	8.63
Carbonate	CO3	Meq/L	NILL	NILL	NILL	NILL	NILL
Bi-Carbonate	HCO3	Meq/L	7.1	6.96	6.54	6.12	5.84
Chloride	CL	Meq/L	3.15	3.13	3.11	3.09	3
Residual Sodium Carbonate	RSC	Meq/L	NILL	0.88	1.21	1.43	1.74
Sodium Adsorption Ratio	SAR	Meq/L	6.28	6.19	6.13	6.09	6.03



(a) **(b)**

Figure. 6: Water Quality Parameters (a) Electrical Conductance, (b) Ca+Mg, HCO_3, Na, Cl, RSC & SAR

4.2 Soil Quality Analysis:

Table. 5 presents an examination of how soil parameters for coriander, lettuce, and spinach are affected by greywater irrigation as compared to samples of fresh soil taken before to harvest. The amounts of total dissolved sodium varied marginally, with values for fresh soil samples being slightly lower at 2.09 to 2.08 dSm-1 and for greywater-irrigated samples ranging from 2.22 to 2.12 dSm-1. These findings demonstrate that greywater irrigation is suitable for irrigation without having a negative impact on salt levels since it does not considerably raise soil salinity.

The pH values of the soil in samples that were irrigated with greywater varied from 7.36 to 7.99, which is a little lower than the pH values of 8.11 to 8.14 in fresh soil. This decrease in alkalinity may increase the availability of nutrients and strengthen the health of the soil. When the proportion of greywater was higher, the amount of organic matter increased generally; in irrigated samples, it ranged from 1.37% to 1.18%, while in fresh soil, it was between 1.11% and 1.12%. According to this, greywater may improve soil fertility by raising organic matter levels.

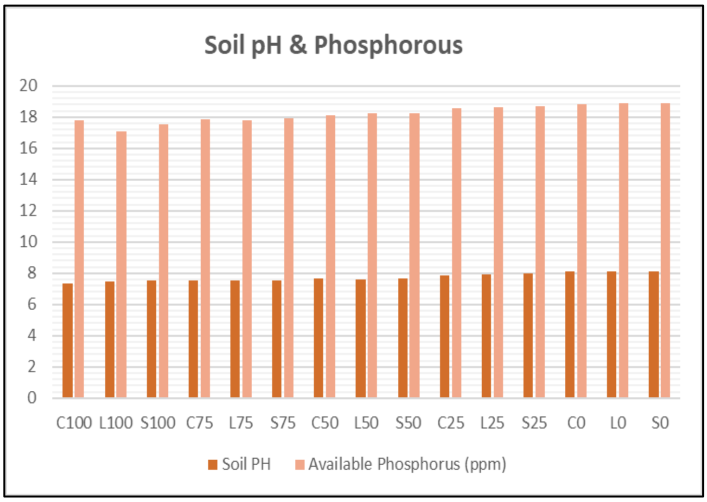
While fresh soil samples had somewhat higher values of 18.85 to 18.86 ppm, available phosphorus levels in greywater-irrigated samples were rather constant, ranging from 17.79 to 18.67 ppm. Greywater-irrigated soils had available potassium levels ranging from 154 to 204 ppm, which were usually greater than the 209 to 210 ppm seen in fresh soil. According to these results, greywater irrigation keeps or improves the availability of these vital minerals, which promotes soil health and plant development.

With larger percentages of greywater, soil saturation percentages increased slightly; in irrigated samples, they ranged from 48% to 42%, while in fresh soil, they were between 42% and 41%. Greywater irrigation did not appear to have a negative impact on soil structure, as the soil texture remained silt for fresh soil samples and clay silt for all samples that were irrigated with greywater. Overall, the findings show that greywater is a good substitute for sustainable irrigation methods since it may help preserve soil fertility and health.

Table 5: Soil Quality Analysis

Tests	Units	Soil after Harvesting of Crops												Fresh Soil		
		C_{100}	L_{100}	S_{100}	C_{75}	L_{75}	S_{75}	C_{50}	L_{50}	S_{50}	C_{25}	L_{25}	S_{25}	C_0	L_0	S_0
Total Dissolved Sodium	dSm-1	2.22	2.23	2.22	2.18	2.21	2.19	2.16	2.14	2.15	2.12	2.10	2.12	2.09	2.08	2.09
Soil PH	-	7.36	7.45	7.51	7.54	7.51	7.53	7.67	7.62	7.69	7.89	7.95	7.99	8.11	8.12	8.14
Organic Matter	%	1.37	1.40	1.38	1.32	1.30	1.29	1.20	1.23	1.21	1.18	1.14	1.15	1.11	1.12	1.11
Available Phosphorus	ppm	17.79	17.11	17.51	17.88	17.76	17.91	18.10	18.25	18.21	18.54	18.61	18.67	18.85	18.87	18.86
Available Potassium	ppm	154	161	152	167	162	168	189	182	190	195	198	204	209	210	208
Saturation	%	48	50	51	47	45	44	45	42	44	44	43	42	42	41	43
Texture	-	Clay Silt	Clay Silt	Clay Silt	Clay Silt	Clay Silt	Clay Silt	Clay Silt	Clay Silt	Clay Silt	Silt	Silt	Silt	Silt	Silt	Silt

C100 Coriander at 100% greywater concentration.
L100 Lettuce at 100% greywater concentration.
S100 Spinach at 100% greywater concentration.



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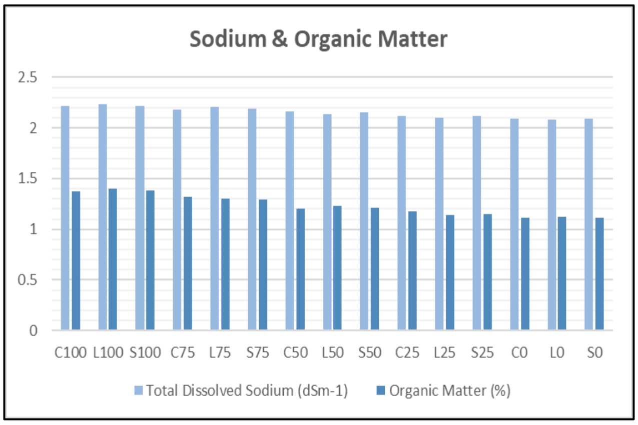

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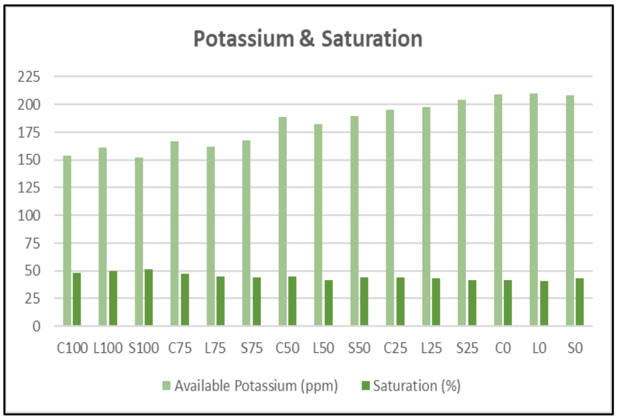

(c)

Figure. 7: (a) Soil pH & Phosphorous, (b) Na & OM, (c) pH & Saturation %

4.3 Crop Quality Analysis:

4.3.1 Coriander:

Depending on the proportion of greywater used for irrigation, coriander displayed different growth and colouring characteristics. The coriander achieved a size of one foot and a pure green hue at 100% freshwater, suggesting ideal growing circumstances. On the other hand, growth was absent when the water was 100% greywater, most likely because of the water's high salt. Coriander sprouted to a height of 5 inches and had a light green to yellowish hue when watered with 75% greywater, indicating some stress but still accomplishing partial growth. The plants expanded to 8 inches and kept their green hue at 50% greywater, suggesting improved adaptability and modest growth. The plants grew 11 inches and kept their green colour at 25%, which was the best growth rate for greywater, nearly resembling the circumstances of freshwater irrigation.

4.3.2 Spinach:

When watered with varying quantities of greywater, spinach showed notable differences in growth and colour. Spinach attained a size of one foot and a vivid green hue at 100% freshwater, suggesting ideal development. Nevertheless, because of the water's high salinity, there was no growth when using only greywater. The spinach, which grew to 6 inches and had a pale green to yellowish tint with 75% greywater, indicated some stress. The spinach grew 8 inches and kept its green colour when it was watered with 50% greywater, indicating improved growth. At 25%, when the plants grew to 11 inches and kept their green colour, the greatest growth with greywater was seen, suggesting that the circumstances were right

4.3.3 Lettuce:

Increased amounts of greywater elicited diverse reactions in lettuce. It grew well, reaching 7 inches and showing green and yellow coloring at 100% freshwater. But because of the high salinity, there was no growth at 100% greywater. The lettuce did not grow much at 75% greywater, indicating that it is sensitive to water and nutrient quality. There was very little, insignificant growth with 50% greywater. The lettuce expanded to 4 inches and retained its green and yellow colour at 25% of its maximum growth rate, which was still less vigorous than with freshwater.

(a) (b) (c) (d)

Figures. 8: (a): at 100% tap water, (b): at 75% tap water, (c): at 50% tap water, (d): at 25% tap water

(a) (b) (c) (d)

Figures. 9: (a): at 100% tap water, (b): at 75% tap water, (c): at 50% tap water, (d): at 25% tap water

(a) **(b)**

Figures. 10: (a): at 100% tap water, (b): at 75% tap water

5. Conclusion

- The study showed that depending on the proportion of greywater used, irrigation with greywater might have different impacts on crop development and soil qualities.
- The research period's climatic circumstances exhibited a range of temperatures and weather patterns, which might have impacted the crops' overall development and health.
- Greywater has a greater salinity and mineral content than tap water, as evidenced by higher levels of electrical conductivity, calcium, magnesium, sodium, bicarbonate, chloride, and SAR in greywater.
- Greywater irrigation results in lower soil pH and higher amounts of total dissolved salt, suggesting that greywater affects the acidity and salinity of the soil.
- Greywater usage was shown to increase the amount of organic matter in the soil, indicating that it might help improve the organic content of the soil.
- The use of greywater resulted in slightly increased amounts of available phosphate and potassium in the soil, which might potentially give the crops more nutrients.
- The findings of crop growth showed that spinach and coriander fared better at lower greywater concentrations, whereas greater greywater concentrations resulted in diminished size and color quality. More delicate than other plants, lettuce grew very little in greywater and thrived in freshwater.

6. Recommendations

Based on the conclusion of this study, several recommendations are proposed to optimize the use of greywater for irrigation. These recommendations aim to maximize the benefits of greywater while minimizing potential risks to soil, crops, and human health.

Regularly test greywater for pH, electrical conductivity, and sodium levels to ensure it remains within safe parameters for irrigation, preventing soil salinization and maintaining soil health.

Prioritize the use of greywater for irrigating non-food crops, ornamental plants, or landscaping to minimize potential health risks associated with pathogens in greywater.

Utilize filtration systems to remove large particles and contaminants from greywater before irrigation to protect soil & plant health and dilute greywater with tap water to reduce the concentration of dissolved salts and nutrients, ensuring a balanced nutrient supply for plants.

Conduct regular soil tests to track changes in pH, organic matter, and nutrient levels, adjusting greywater application rates to maintain optimal soil conditions.

Use drip or subsurface irrigation systems to deliver greywater directly to the root zone, reducing the risk of foliar contamination and evaporation losses.

Provide education and training on safe greywater use, including the importance of avoiding direct contact with edible parts of plants and using greywater only for appropriate crops.

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