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Exploring greywater hydroponic vegetable growing and phytoremediation capacity of coleus plants for urban farmers in Mbarara city Uganda

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Abstract

Sustaining the escalating urban population in food and nutrition security remains a global concern. Urban farming, which maximizes production using limited resources, is the right option for urban populations in developing countries. Between July and September 2023, an eight-week experiment to establish the capacity of greywater as a hydroponic medium to grow vegetables for human consumption and test the greywater cleansing capacity of Coleus ornamental plants was conducted. The motivation was to pilot an intervention to the challenges of land, water, space, malnutrition and wastewater disposal in Mbarara. Broccoli, Spring onions and Lettuce were used and greywater was collected from restaurant sculleries in Mbarara. Four treatments: Greywater, Greywater + NPK, Tap water, and Tap water + NPK were prepared and vegetable seedlings assigned in triplicates to each. The pH, EC, TDS, Temperature, Turbidity, Nitrates and Phosphates of the growing media; shoot length and number of leaves for the test vegetables and fecal coliforms and heavy metal in the media and plant tissues were tested following standard procedures. All vegetables survived but the levels of production differed significantly between treatments. Lettuce had the highest production in three treatments except GW+NPK (ANOVA shoot length ($F (3, 56) = 2.970, p = 0.039$). Spring onions grew best in greywater + NPK significantly differing from other treatments, ANOVA ($F (3, 56) = 3.328, p = 0.026$). Extreme EC and TDS values (1001.38 µS/cm and 502ppm; and 982.38 µS/cm 490.75ppm) were recorded in greywater treatments and significantly differed from other treatments ($p = 0.000$). No fecal coliforms were detected in the vegetable tissues. Coleus progressively reduced the TDS and EC and exhibited capacity to extract heavy metals from greywater. Greywater is a viable hydroponic medium to grow vegetables. It is recommended that greywater nutrient enhancement to improve production for specific vegetables and use of Coleus plants for hydroponic greywater remediation.

Keywords: *Coleus; Greywater; Hydroponics; Mbarara; Phytoremediation; Urban farmers*

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Introduction

The global human population stood at eight billion (UN, 2023), 85 percent of which was estimated to be living in or within reach of an urban centre (Djan, 2023). The number of inhabitants that live in small cities alone is expected to reach a total of 2.08 billion by 2030 (Djan, 2023). As postulated by Vardoulakis and Kinney (2019), over half of the global population is urban-based and the figure is projected to keep rising.

In sub-Saharan Africa alone, the annual increase in the urban population is a steep 3.5% (Jamal and Jena, 2018). Uganda's population as of the 2014 National census was 34.6 million, and is now at **46+ million** according to the current Worldometer figure (Uganda Bureau of Statistics, 2024). Twenty-six percent of Uganda's population is classified as urbanized and is projected to double by 2030 given the fast growth of 4.5% per annum (UN-HABITAT Uganda, 2023). Uganda has 202 urban areas and recently proposed 15 of her towns for city status out of which seven have been elevated including Mbarara city (UN-HABITAT Uganda, 2023). Many people migrate to urban areas in search of better social services, employment opportunities and better life in general (Sotiris and Patrick, 2019) and the gazettement of regional cities by the government of Uganda has paved way for more people to migrate to these centers including Mbarara whose city status was officially operational in July 2020.

Mbarara City is Uganda's fastest growing town outside the Kampala Metropolitan Area. With the rapidly expanding population Mbarara city is tasked to respond to a number of challenges especially adequate water supply, food and space/land, (Mbarara District development plan 2020/2021-2024/2025).

While food and nutritional security are a basic requirement in any human society, the urgency to sustain the escalating urban population in the area of food and nutrition remains a global concern (Djan, 2023). Malnutrition was still factored as an outstanding challenge in the then Mbarara Municipality (Sengendo *et al.,* 2012). The bulk of Mbarara city dwellers do not have stable economic bases to earn enough money for food and general sustenance. Those who cannot afford to buy food in the market resort to supplementing their income with small-scale agriculture. The urban dwellers have a challenge of limited land to farm or no land at all for those who live in rented premises. Urban farming, whose ultimate aim is to maximize production using limited resources, is one intervention earmarked to improve the livelihoods of urban populations in developing countries (Ghaly *et al.,* 2021; Hubert de Bon *et al.,* 2009).

The need to address hunger and poverty especially among the less privileged men, women and youth of Mbarara underpins the governance priorities, (Uganda National Planning Authority, 2020). However, the proposed standards for urban farming may not be accessible for some of the intended beneficiaries. The proposed irrigation for example, may not be affordable especially by the resource-constrained households. Additionally, access to adequate water supply for irrigation may not be sustainable because being in the dry cattle corridor, semi-arid conditions characterize Mbarara region where incidences of prolonged drought, irregular and scant rainfall among others are common (Nalukwago, 2019). Mbarara has few natural water bodies apart from River Rwizi and a few wetlands; consequently, adequate freshwater supply continues to be strained as the demand increases (Mukombozi, 2022). River Rwizi itself is on the verge of drying up due to the effects of anthropogenic activities (Atwebembeire *et al.,* 2019); this undermines the sustainability of irrigation as an option in urban farming in Mbarara city.

Greywater is defined as domestic wastewater that is uncontaminated by direct contact with human excreta (Ghaly *et al.,* 2021) and hydroponics is a farming system where water is used as a plant growing medium instead of soil. We proposed a greywater-based hydroponics technology as an urban farming option that could address the nutritional, economic and land shortage challenges faced by the resource-constrained smallholder urban farmers in Mbarara city. Hydroponics is a resource-effective and user-friendly vegetable and green fodder production technology ideal for persons who have limited or no personally owned premises (Gumisiriza *et al.,* 2022). Hydroponics saves water by 80% compared to conventional irrigation, and negates the need for vast space and many farm management chores as required in outdoor farming. Hydroponics is an option in agriculture that uses minimal resources like space, cheap water supply and basic skills (Prashanthini *et al.,* 2021).

A brief but purposive survey through Mbarara town smallholder urban farmers revealed that there was no established hydroponic system for either horticultural or animal feed production and most people contended that they were not familiar with the practice (Justus *et al.,* 2023). The hydroponics technology could be tailored for adoption by the youth and women groups in the poorest sections of the city in line with the priority of "Deliberate economic empowerment of women and the youth" (Uganda National Planning Authority, 2015) and Sustainable development goals especially number 1 and 2.

While hydroponics is an option that could be harnessed to alleviate the challenge of limited land/space in resource-constrained urban communities, the challenge of water supply to support hydroponics remains. One way around this challenge is the use of domestic greywater generated from the kitchen and laundry activities of the said households. Greywater includes wastewater from non-toilet systems like kitchen sinks, shower and laundry drains.

The motivation behind this study was to make a contribution in responding to the challenges of wastewater disposal, shortage of land and water for agriculture, and malnutrition faced by resource- constrained urban communities in Mbarara City. Two target populations: small-scale restaurants challenged with wastewater disposal since most are not connected to city plumbing system, and the resource-constrained urban farmer communities who are defined by limited land/space for agriculture; scarcity of water for domestic use, adequate food and irregular income.

In this study, the authors sought to establish the potential of restaurant-generated greywater as a hydroponic medium for growing leafy vegetables (Widiyanti *et al.,* 2020) and to test the potential of *Coleus spp*, a common ornamental plant in the area, to remediate greywater used in hydroponics.

The four objectives of the study were to establish the quality status of the greywater in a hydroponic medium, the growth performance of three common leafy vegetable varieties (Lettuce, Broccoli and Spring onions), the microbial safety of the grown vegetables and finally the capacity of ornamental Coleus plants to improve the quality of greywater. We picked on *Coleus spp* to test its capacity in cleaning up greywater because it is one of the terrestrial plants that have phytoremediation properties (Prerna *et al.,* 2019), and is readily available in the region.

The findings of this study form a basis to advance the greywater-based hydroponic technology and offer it for adoption among smallholder urban households in Mbarara city. The long-term purpose is to empower the economically vulnerable people in Ugandan urban areas.

Materials and Methods

Study area

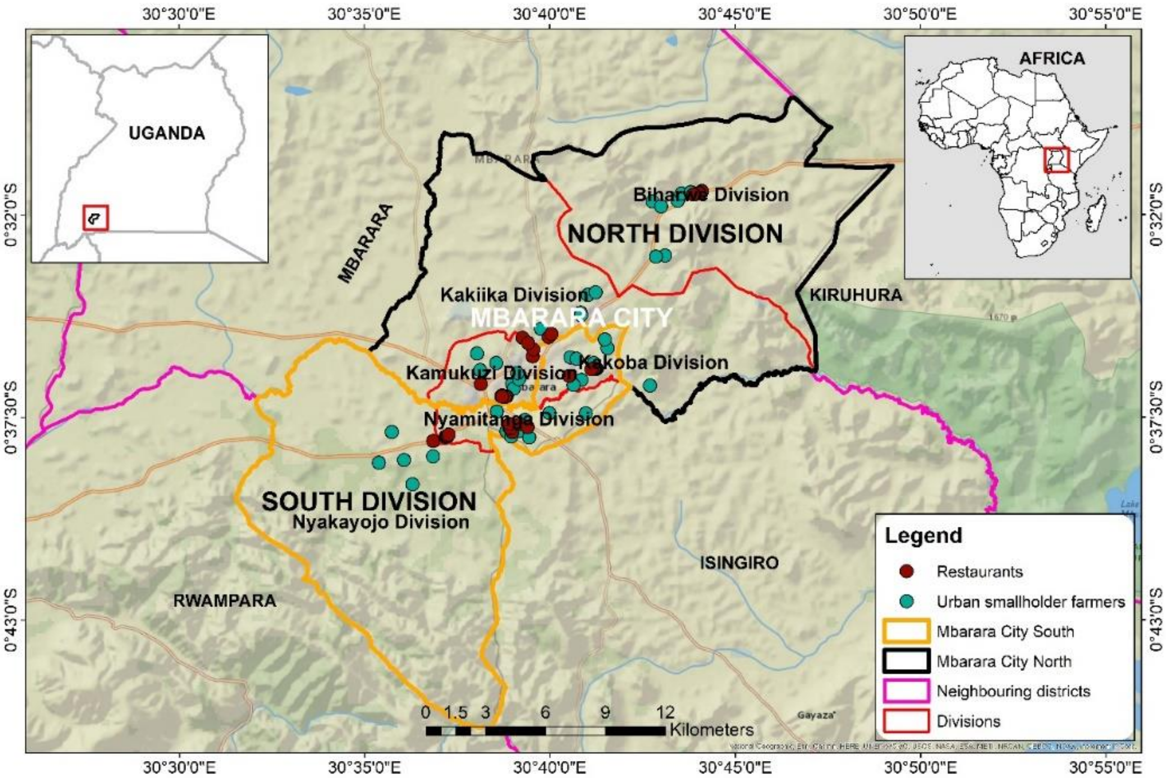
The study was premised at Mbarara University of Science and Technology (MUST) Town Campus (Latitude: 00° 37' 0.59" N Longitude: 30° 39' 14.39" E) in the Biology laboratory of Faculty of Science in Mbarara City Southwestern Uganda.

Greywater collection

The greywater used in the study was collected from sculleries of small-scale restaurants in Mbarara City North and Mbarara City South, the two divisions that constitute Mbarara City (Figure 1). Purposive sampling method was used based on the willingness of the restaurant proprietors to allow us collect the water from their sculleries. Ninety litres of greywater was collected and carried to the laboratory for subsequent use in the experiment.

Figure 1

Map of Mbarara City Showing the North and South Divisions where the Greywater samples for the Experiment were picked (red dots)



Hydroponics Experiment setup

Preparation of the culture system

The Kratky method of the Deep Water Culture system was adopted (Gumisiriza *et al.,* 2022), due to its efficiency, ease of application and minimal costs of setup and maintenance (Pandey, and Singh, 2011). Forty litres of greywater and forty litres of tap water were prepared into four treatments as detailed below:

Treatment 1 Greywater only (GW): Twenty litres of the already collected greywater was sieved using a plastic sieve of about 500 µm.

Treatment 2 Greywater plus NPK (GW+NPK): another twenty litres of greywater was sieved and mixed with liquid NPK at a concentration of 1ml/litre.

Treatment 3 Tap water only (TW): Twenty litres of tap water was collected from the tap in the laboratory supplied by National Water and Sewerage Corporation of Uganda.

Treatment 4 Tap water plus NPK (TW+NPK): Twenty litres of tap water was mixed with liquid NPK at a concentration of 1 ml/litre of water.

From each of the prepared media was drawn the amounts to fill the hydroponic vegetable growing troughs with capacity of ten litres each. The media that remained for each treatment was used for replenishment whenever there was need.

Preparation of the experimental plants

Three vegetable varieties, Lettuce (*Lactuca sativa*), Broccoli (*Brassica oleracea*), and Spring onions (*Allium fistulosum*), were propagated to seedling stage before the commencement of the experiment. Commercial seeds were purchased from an established Farmers' Agro-shop in Mbarara city and aseptically planted under conducive conditions to produce healthy seedlings. A section of a garden with good loamy soil was used to prepare three seed beds of about $1m^2$ for each of the experimental vegetables. The soil was leveled and cleared of soil lumps and raised up to about 15 cm above the ground level. Four to five shallow, evenly spaced rows of about 1.5 cm, were made and seeds were spread evenly along the rows and covered with a thin layer of soil. A grass thatched structure of about I metre height was constructed above the seed beds to ensure soil moisture retention and prevent desiccation of the seedlings. The seed beds were gently and evenly watered twice a day. Spring onions were propagated two weeks before the others because they take longer to reach the transplanting stage.

Preparation of the experimental hydroponic garden

New disposable plastic cups of about 5cm (H) by 12 cm (W) were used to grow the vegetables. Each cup was perforated on the bottom and sides to allow movement of water and air. Clean ten-litre basins were used to hold the water (growing medium) for each treatment. Each of the basins was covered with a wooden frame which was purposely designed to securely hold the plastic cups that contained the growing vegetables.

The seedlings were randomly distributed into each of the 4 treatments. Two seedlings for lettuce, broccoli and -three seedlings for spring onions were planted in the growing cups in triplicates. The plants were held in position by cleaned and disinfected pebbles sprinkled on top with sawdust to absorb moisture (Masoud *et al.,* 2012).

Coleus plant collection and planting

We used *Coleus spp*., a common ornamental plant in the area, to test its potential of to extract water pollutants like heavy metals and excess salts from greywater thereby rendering it safe for use in hydroponics. The Kratky deep-water hydroponic system was also adopted for this setup. Eight litres of greywater was obtained from the already collected lot and put in clean 10 litre buckets. Vines of variegated *Coleus spp* (Figure 2) were collected from mature Coleus potted plants, and planted in clean disposable cups with a hole to let the vine touch the water. The vines were also held in place by clean and disinfected pebbles. A paper cardboard was perforated and placed on top of the bucket containing greywater to hold the cups (Figure 2). The efficiency of phytoremediation was established by monitoring changes in key physicochemical parameters of the greywater in which the coleus was growing.

Data collection

Data from the vegetables in the hydroponics experiment

On the day of transplanting; the total shoot length (cm), root length (cm), number of leaves and total weight (g) for each vegetable seedlings were recorded and thereafter, the production indices including shoot length, number of leaves, general appearance and survival were recorded after every five days.

The quality of the water in each of the four treatments was tested weekly for pH, Electrical Conductivity (EC), Total dissolved solids (TDS), and temperature, while dissolved oxygen (DO), colour, turbidity, phosphates and nitrates were tested at the start, mid-way and end of the experiment. A Hanna Multi-probe meter and pH/EC/TDS test probe were used.

At the end of the experiment, the microbiological safety of the greywater medium and the harvested leaves of the experimental vegetables were assessed by testing for *Escherichia coli*, a fecal contamination indicator microorganism. (Figure 3).

Figure 2

*Coleus vines that were planted in Greywater (**left**), the Planted vines (**centre**) and an already growing Coleus plant (**right**)*

The greywater cleansing efficiency by *Coleus spp*. was assessed. Two varieties of Coleus plant cuttings (purple and green) were planted in untreated restaurant generated greywater. The aim was to establish whether these plants would survive and /or later on utilize the excess dissolved solids in the greywater medium and to extract heavy metals potentially present in the greywater generated from restaurants. We tested for the presence of coliform bacteria as well as heavy metals in the plant tissue. The growing medium was tested for EC, TDS and pH over the entire experimental period.

Figure 3

Microbial analysis Plates for detection of Total Coliforms, Fecal Coliforms and E. coli in Greywater and Leaf extracts from Coleus, Spring Onions and Lettuce

For microbial contamination, specifically the presence of *E. coli*, samples were processed following standard procedures (Serkan and Buyukunal, 2015). Twenty-five (25) grams of composite samples of lettuce, spring onions, and Coleus leaf samples were aseptically harvested, rinsed in distilled water and separately packed in sterile zip lock bags. The samples were then taken for analysis within one hour after collection. Ten (10) grams of each sample was weighed into a stomacher bag. Each sample was then diluted by adding 90 mls of buffered peptone water (BPW). The samples were then homogenized for 2 mins at 230 revolutions per minute (RPM) using a Stomacher. They were then held by placing them in a rack for 30 mins before analysis was performed. 1ml of the BPW from each sample was picked in duplicate and pipetted to a petri-dish. Microbial growth was then enumerated and results reported as colony forming units per ml (cfu/ml).

For the determination of *E. coli*, the Pour plate method was used where Tryptone Bile X-Glucuronide (TBX) agar was added until the base of the dish and sample was covered, and the dish was swirled in different directions to ensure proper mixing of the sample and the media. For the determination of total coliforms, the pour plate method was used where Violet Red Bile

Lactose Agar (VRBL) was added until the base of the dish and sample was covered, and the dish was swirled in different directions to ensure proper mixing of the sample and the media. The control plates for the media were prepared by pouring the liquid agar on petri dishes that did not contain any sample. The plates of TBX were then placed in an incubator set at 44°C for 24 hours while those of VRBL were placed in an incubator set at 37°C for 24 hours, and afterwards observed for any signs of microbial growth. The resulting *E. coli* culture was enumerated from the homogenized supernatant using the most probable number method (MPN) with Colilert-18(IDEXX) and Quantitray 2000 (IDEXX) according to ISO9308-2:2012.

Analysis of heavy metal uptake by Coleus plants

Since the greywater hydroponics vegetables are meant for human consumption, it was important to test options of cleaning the greywater. In this we used *Coleus spp* of indoor ornamental plants as potential phytoremediators for greywater for use in hydroponics. The concentrations of heavy metals Pb, Zn, Cu and Ni in the greywater and plant tissues were determined using Atomic Absorption Spectrophotometry (AAS) method.

Statistical analysis

All the collected data was recorded in MS Excel 2016 spreadsheets. The comparative and descriptive analyses were done with IBM SPSS Version 26; the significance was upheld at $p < 0.05$. Data sets were tested for normality using the Shapiro-Wilk test ($p > 0.05$); variations were tested using the analysis of variance (ANOVA) having established that they were normally distributed. Data on plant production indices, microbial quality and heavy metals were analyzed using exploratory data analysis (EDA) approach and presented in tables, line and bar graphs.

Results

Quality of the water in the different treatments over the experimental period

High values of EC, TDS, Salinity, Turbidity and Colour were registered for treatments I Greywater only (GW) and treatment 2 Greywater + NPK (GW+NPK). There was a statistically significant difference in pH, EC and TDS between the four treatments ANOVA pH ($F(3,28) = 3.354$, $p = .033$); EC ($F(3,28) = 24.023$, $p = .000$); TDS ($F(3,28) = 14.899$, $p = .000$); a post hoc Tukey test showed that treatment 1 (GW) and 2 (GW+NPK) differed significantly from treatments 3 (TW) and 4 (TW+NPK) $p < .05$. There was no significant difference in temperature between all the treatments.

Details of the physical-chemical parameters of the growing medium in the four treatments recorded over the period of eight weeks are presented in Table 1 and 2.

Nitrate was very low in Treatment 1 and 3 (GW and TW) but high in Treatment 2 and 4 (GW+NPK and TW+NPK), the details are presented in Table 2.

Production capacity of the three vegetable varieties

Results of the production capacity were based on 5 weeks only to allow better comparison between the three vegetable varieties because lettuce tended to mature faster. In Spring onions, a continuous trend of increase in shoot length was observed in all the four treatments. However, there was a slight but statistically significant difference between the treatments; ANOVA ($F(3, 56) = 3.328$, $p = 0.026$) and the difference was between treatment 1 (GW) and 4 (TW). Treatment 4 (TW + NPK) had the highest means for shoot length followed by treatment 2 (GW + NPK). Treatment 2 had the highest mean number of leaves followed by treatment 4 (Figure 4 a). Both shoot length and number of leaves were better in treatments that had NPK, this is a probable indication that NPK was responsible for the better growth in Spring onions.

Table 1

Means of Four Basic Water Quality Parameters for each Treatment measured Weekly through the Experiment Period

PARAMETER	TREATMENT	MEAN	Std. Err
pH	1. GW	6.3238	0.3212
	2. GW+NPK	6.7525	0.27621
	3. TW	6.56	0.10195
	4. TW+NPK	5.775	0.15427
EC	1. GW	**1001.38**	104.873
	2. GWLM	**982.38**	125.891
	3. TW	146.75	4.585
	4. TW+NPK	377.5	64.627
TDS	1. GW	**502**	52.461
	2. GW+NPK	**490.75**	63.032
	3. TW	73.38	2.306
	4. TW+NPK	189.5	32.117
Temp	1. GW	25.4125	0.38704
	2. GW+NPK	25.6512	0.41561
	3. TW	25.2675	0.35161
	4. TW+NPK	25.9388	0.52526

Table 2

Turbidity, Colour, Nitrate and Phosphate Concentrations in the four Treatments

PARAMETER	TREATMENT	Mean	Std. Error
TURBIDITY (fnu)	GW	**34.267**	20.1843
	GW+NPK	**62.700**	29.0083
	TW	2.200	.5000
	TW+NPK	1.967	.3333
COLOUR (pcu)	GW	**312.33**	72.676
	GW+NPK	**228.33**	52.695
	TW	20.00	9.165
	TW+NPK	18.00	5.508
NITRATE (mgl)	GW	**2.0000**	1.52753
	GW+NPK	45.0000	37.52777
	TW	**.0000**	.00000
	TW+NPK	46.6667	36.66667
PHOSPHATE (mgl)	GW	1.3333	.33333
	GW+NPK	2.5667	1.27323
	TW	.7000	.15275
	TW+NPK	3.3333	.88192

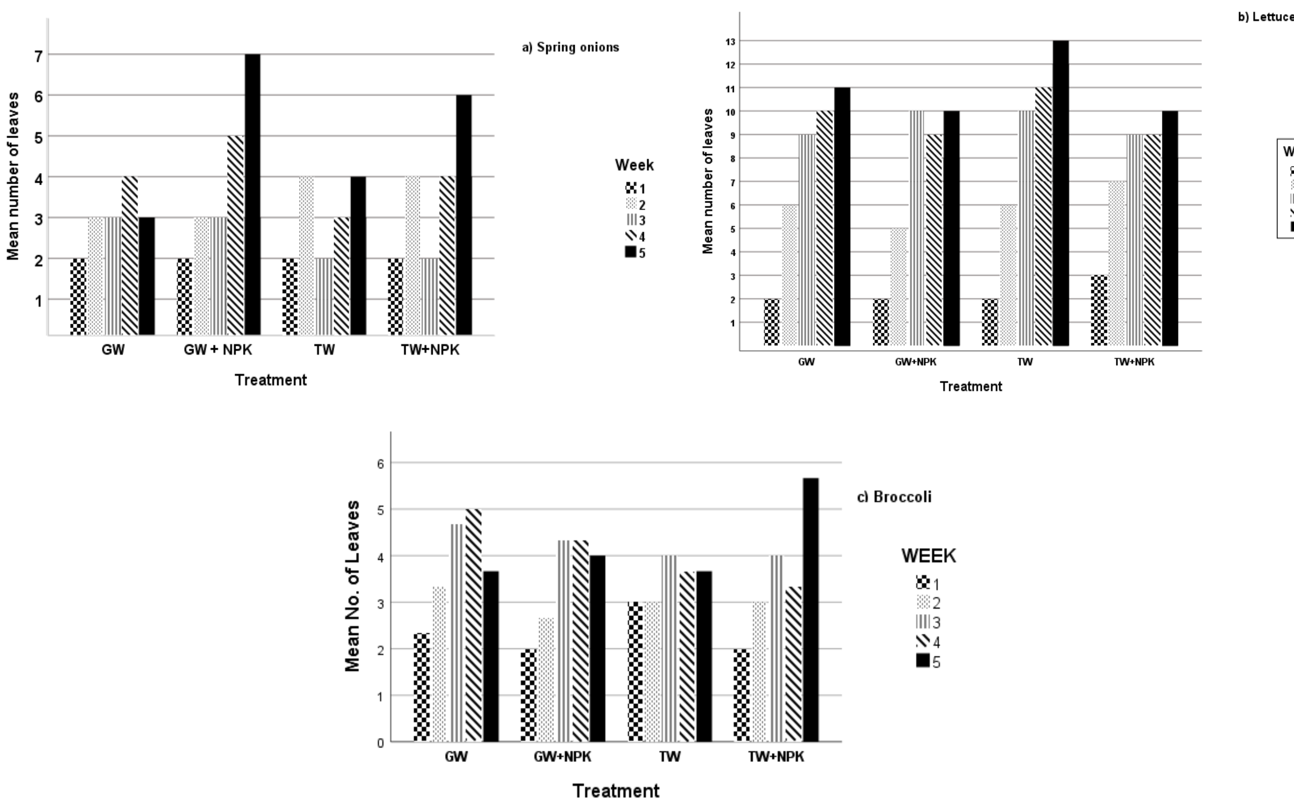
GW (Greywater); GW+NPK (Greywater + liquid NPK), TW (Tap water) TW +NPK (Tap water + Liquid NPK)

There was a slight difference in the mean shoot length of lettuce across all the treatments and no significant difference in the number of leaves; ANOVA shoot length ($F(3, 56) = 2.970$, $p = .039$); Number of leaves ($F(3, 56) = 0.98$, $p = .407$) Figure 4 b). The Tukey's post-hoc test indicated that the differing means in shoot length were from treatment 2 (GW+NPK). The most probable cause of the shoot becoming very long could be the insufficient lighting causing etiolation, since the experiment was indoors, or the over enrichment of the growing medium.

For Broccoli, we present only the number of leaves because the results from shoot length were not representative enough since a number of the stems were slender and elongate leading to breakages in some treatments. The number of leaves were more in treatment 1 (Figure 4 c), but the difference between treatments was no statistically significant. ANOVA number of leaves ($F(3, 43) = 0.331$, $p = .803$). The possible explanation for the elongate stems could still be etiolation.

Figure 4

Production Capacity in terms of Mean number of Leaves for ***a****) Spring Onions* ***b****) Lettuce and* ***c****) Broccoli over the first Five Weeks of the Experiment*



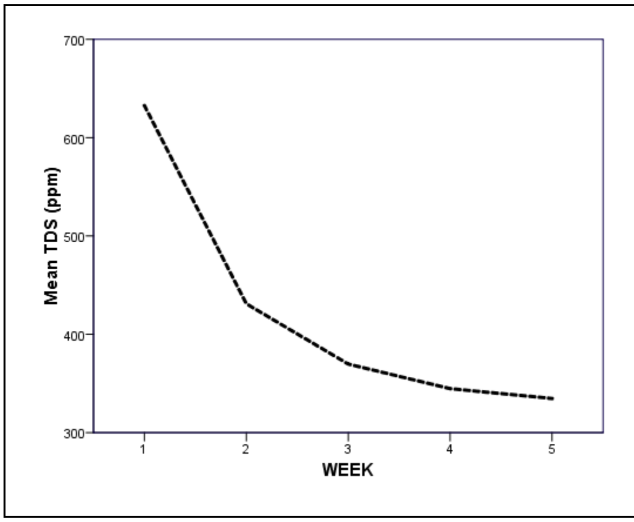
**(GW (Greywater); GW+NPK (Greywater + liquid NPK), TW (Tap water) TW +NPK (Tap water + Liquid NPK*

Greywater cleansing capacity by Coleus plants

The concentrations of electrical conductivity (EC) and total dissolved salts (TDS) of the greywater medium where we planted Coleus cuttings showed progressive reduction over the five-week period as depicted in Figure 5.

Figure 5

Means of Total Dissolved Solids (TDS) and Electrical Conductivity (EC) in the Graywater medium where Coleus plants were growing



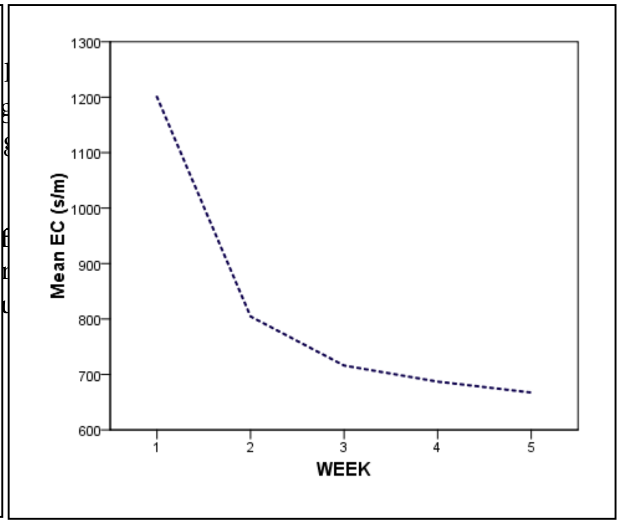


Table 4

Mean concentration of Four Heavy Metals in the tissues of Coleus varieties and Spring Onions extracted from the Greywater in which they were growing

Plant ID	Metal ID	Mean concentration (mg/Kg)
Coleus green	Pb	1.381
Coleus purple	Pb	1.172
Coleus green	Zn	18.974
Coleus purple	Zn	14.626
Coleus green	Cu	1.449
Coleus purple	Cu	1.605
Coleus green	Ni	ND
Coleus purple	Ni	ND

Table 5

Microbial Status of Greywater used as the Hydroponic medium for Spring Onions and Coleus

Sample ID	**Coliforms**	
	Total coliform/100 mls	E coli
1. GW R	+1800.0	0.0
2. GW So	50.0	0.0
3. GW C	35.0	0.0

1. GWR: Raw greywater; 2. GWSo: Greywater from the tank with Spring onions; GWC: Greywater from the tank with Coleus

Table 6

Microbial Status of Lettuce, Spring Onion and Coleus spp Grown in Greywater

Sample No.	Sample ID	Total coliforms	Result (cfu/g)	E. coli test	Result (cfu/g)
1	Lettuce in GW	TNTC*	TNTC	0	<10
2	Spring onions in GW	TNTC	TNTC	0	<10
3	Lettuce in TW (Control)	0	<10	0	<10
4	Coleus in GW	0	<10	0	**<10**
5	Media blank	**No growth**		**No growth**	

Sample plates number 1 and 2 *had some atypical colonies i. e growth that was not characteristic of E. coli thus it probably had other gram-negative organisms but not E. coli. Presence of coliforms was determined by the growth of pink colonies that changed the color of the media. TNTC was used to denote plates that had counts above 300 colonies*

Discussion

The broad aim of our study was to test the potential of greywater as a hydroponic medium to grow short term leafy vegetables, establish the safety of these vegetables for human consumption and gauge the capacity of Coleus in improving the quality of greywater to make it more suitable for vegetable growth. This is envisaged as a viable contribution to the quest of addressing the land, water, space, nutrition and waste water disposal challenges faced by urban communities in Mbarara city.

The study findings affirm that it is possible to locally grow edible vegetables hydroponically and that greywater can be used as a growing medium as testified by earlier studies like (Eregno *et al.*, 2017; Widiyanti *et al.*, 2020). While hydroponics is promoted as a viable option for highly populated urban communities (Libia and Fernando, 2012), use of greywater as a growing medium becomes even more viable for urban centers like Mbarara city where scarcity of water for the community is already a problem. Mbarara city, being located in a semi-arid cattle corridor; has to adopt water re-use strategy proposed for such regions (World Health Organization, 2006) and the findings of greywater-based hydroponics experimented in this study provides a benchmark.

Since we collected the greywater from restaurant sculleries where salt, oil, detergent and soap residues are expected, the concern raised by the high values of turbidity, EC, pH and TDS is be partly explained (World Health Organization, 2006). In fact, the quality level of the greywater we used falls within the expected ranges as reported by other studies (Ghaly *et al.*, 2021). To manage such undesirable quality attributes that most likely contributed to the reduced growth and health of the test vegetables, purposive selection of water intended for hydroponics is recommended (Ghaly *et al.*, 2021) as well as application of some basic treatment strategies like phytoremediation (Bihola *et al.*, 2020).

Traces of heavy metals detected in the tissues of Coleus may be attributed to some detergents used restaurants since they are known to be the main sources of heavy metals in greywater (Ghaly *et al.*, 2021). Since heavy metals pose a health risk in human beings (Ghaly *et al.*, 2021) the capacity of *Coleus spp* in taking them up offers an important safety aspect for potential users of greywater based hydroponics. That's why we would recommend local remediation strategies like use of *Coleus spp* whose chemical and biological cleansing capacity was established in this study and backed by a number of studies like Bihola *et al.*, (2018); Masoud *et al.*, (2012) and Bismelah *et al.*, (2019). In addition to cleaning the greywater, the Coleus can be used for commercial purposes as ornamentals.

Regarding contamination, the reservations to use greywater for human food are largely premised in possible microbial contamination (Eregno *et al.*, 2017) but it is not always the case as affirmed by this and other studies e.g the findings of Ezzahoui *et al*., (2021) and (Lopez-Galvez *et al*., 2016). The tests on greywater samples used in the study did not present any detectable *E. coli*, rendering the grown vegetables safe for human consumption. However, for safety purposes, choice of greywater for vegetable hydroponics must be done with care to avoid chances of microbial contamination. The likelihood of contamination with coliforms is expected depending on the greywater source (World Health Organization, 2006) and caution ought to be taken.

The choice of vegetables in this pilot study was motivated by the fact that despite the important role vegetables play in human nutrition (Abbas *et al.,* 2011), many households in Mbarara city do not grow vegetables; implying that inclusion of vegetables in their diet is minimal. This may partly explain why the region is still ranked among regions with high rates of malnutrition (UN-HABITAT Uganda, 2023). If adopted, the option of hydroponic vegetable growing would relieve the already known burden of malnutrition, especially among children and pregnant women, in Mbarara city. From the production of the vegetables, it is true that greywater does support their growth. Lack of some essential nutrients in greywater has been established by some studies (Prashanthini *et al*., 2021) and this may explain why spring onions in this experiment grew better in the media added with NPK.

Being in a soilless medium, the harvested vegetables were clean and would require less water to wash them, an advantage in an area where water scarcity is the norm. We did not use pesticides since there were low chances of pests and diseases (Baddadi *et al*., 2019; Barbosa *et al*., 2015) . Hydroponics allows the growing of crops without pesticides and could prompt smallholder farmers to trust, and adopt them, and enhance food security in urban households from low-resource settings. In addition, hydroponic farming in a soilless setting reduces environmental impacts compared to soil cultivation as the latter uses pesticides and fertilizers (Barbosa *et al.,* 2015) As the world grapples with climate change, pests, and diseases in crops that significantly reduce crop yields, a hydroponic system could reap big for smallholder farmers whose economic ambitions are heavily retarded by these challenges.

Conclusion

The key outcome of this study is that restaurant-generated greywater can hydroponically support growth of vegetables which are safe for human consumption. The scarcity of water in Mbarara city coupled with the increasing urban population, challenge of greywater disposal especially in small-scale restaurants in makes this option very relevant and timely. It has also been demonstrated that greywater can be treated locally at no monitory cost using Coleus ornamental plants specially to reduce the concentration of dissolved elements that may be harmful to human health.

It is recommended that greywater intended for hydroponic vegetables growing should be collected from known sources to avoid possible contamination. It is also important to establish the specific nutrient requirements for the choice vegetables and enrich the greywater with the lacking nutrients for better and faster yields.

It is also recommended that future experiments could consider outdoor settings, especially for vegetables like Broccoli that take long to mature. This is because it is suspected that limited lighting could have caused incidences of etiolation in the test vegetables.

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