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Domestic Greywater Irrigation on Soil Properties and Enzymatic Activities

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field investigation was undertaken during the Rabi season of 2019-20 in a selected farmer's field at Yelavatti village, near Shivamogga City, Karnataka, India to evaluate the effect of domestic greywater irrigation on soil properties and enzymatic activity. Four types of irrigation water were used for this investigation: greywater, treated greywater, structured greywater, and bore well water (as a control). The results revealed that treatments that received irrigation with domestic greywater significantly improved soil reaction (pH), electrical conductivity (EC), soil organic carbon (SOC), and soil available nutrient status at all growth stages of the Okra vegetable grown soil. The plots which received domestic greywater irrigation alone recorded significantly higher soil organic carbon with 5.92 g/kg, 6.67 g/kg, 6.57 g/kg, available nitrogen with 240.58kg/ha, 281.29 kg/ha, 325.29 kg/ha, available phosphorous with 78.15 kg/ha, 89.54kg/ha, 105.67 kg/ha and available potassium with 317.56 kg/ha, 421.84 kg/ha and 449.53 kg/ha at 30DAS, 60DAS and 90DAS respectively. Domestic greywater irrigation alone treatment recorded significantly higher dehydrogenase activities with 28.72µg TPF g-1 of soil day-1. 32.59 µg TPF g-1 of soil day-1, 35.87 µg TPF g-1 of

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soil day-1, phosphatase activity with 31.73 PNP g-1 soil hr-1, 35.89 PNP g-1 soil hr-1, 39.47 PNP g-1 soil hr-1 and urease activities with 321.39,355.61 and 359.07 µg NH4+ g-1 soil hr-1 at 30 DAS, 60 DAS, and 90 DAS respectively. A similar trend of results was also observed in exchangeable Ca, Mg, and available S as well as DTPA-extracted Zn, Cu, Mn, and Fe in the soil at all growth stages. Irrigation with bore well water alone recorded significantly lower levels of soil pH, EC, SOC, soil available nutrients status, and enzyme activities at all stages of the crop growth. Safe with minimum treatment in the use of domestic greywater irrigation is the best option to mitigate the water crises in future days agriculture.

Keywords: Domestic greywater; soil chemical properties; enzymatic activity; nutrients status.

1. INTRODUCTION

Good quality water is the most essential, but least obtainable natural resource in this era. The expeditious population growth demands a high rate of water supply in each sector. But water availability is lowering very rapidly hence existing water recourse can't full fill these needs. India is also facing this water crisis and by 2025, it is estimated that the Indian population will be facing difficulty from severe water scarcity. Rainwater harvesting and greywater reuse are viable options to vanquish this obstacle. The limitation of rainwater harvesting is that it applies to only the areas that receive high rainfall throughout the year. Hence domestic greywater reuse is the next best gainful option to rectify the water scarcity issues. Greywater is the used domestic water (houses, hotels, restaurants, lodges *etc*.) which comprehends water from kitchen area (7 %), bath and shower (49 %), sinks (7 %), laundry (17 %), dishwashers (10 %). Greywater contributes the largest proportion of household wastewater in terms of volume. Typically, 50-80 percent of household wastewater is greywater [1]. The composition of greywater varies greatly with its origin [2]. Even from the same house, the greywater produced each day may differ slightly. As this water contains many contaminants, organic material, and suspended material it has a grey color, hence it is recognized by the name greywater. Greywater is differing from black water; greywater contains all household water except toilet flush. But black water includes fecal contamination also. Hence reuse and recycling of greywater is more facile than the use of black water. Rural India on average generates about 31,000 Million liters of greywater on a daily basis and urban India areas generate 61,948 million liters (MLD) a day [1]. If such greywater collect properly it can be recycled and can be used for many purposes such as crop production, gardening, toilet flushing, *etc*. Hence it conserves the existing freshwater level to a great extent, environmental pollution can be reduced, also when it is used as irrigation water, it indirectly improves soil fertility compared to freshwater irrigation as it contains many nutrients. The continuous use of greywater in the agriculture field may change the soil properties and characteristics of the crop grown in the soil. There was no systematic research study on domestic grey water irrigation and its effect on soil properties in the Indian context. Hence this experiment was conducted to know the impact of greywater irrigation on soil properties and enzymatic activities.

2. MATERIALS AND METHODS

The field experiment was conducted at Yelevatti village, peri-urban areas of Shivamogga city, Shivamogga district, Karnataka, India. The greywater generated in the farmer's house was collected for analysis. The required treatment of that collected greywater was done using filtration units that were established in the same house. Domestic greywater generated from the house was collected into the main tank. From this tank, the water was passed into the remaining tanks installed for the filtration process. Materials such as sand, gravel, and activated charcoals were filled from bottom to top of the filtration unit layer-wise systematically for filtration of the household grey water. Phytroid plant species such as cannas plant and umbrella palms were also planted in the filtration tank. After filtration, the treated greywater was collected in the tank located at the end and pumped to the syntax tank located on the roof of the house. To get structured greywater, the treated greywater was passed through a structural unit device. This structured greywater was also pumped to another syntax tank located on the roof of the house. These three types of water along with bore well water (as a control) were used for the irrigation for the cultivation of Okra vegetable crops. All four types of irrigation water were analyzed for chemical properties before treatments imposition and results as well as methods of analysis are given in table (Table 1).

The field experiment was conducted with nine (09) treatments in three replications with Randomized complete block design (RCBD). Four types of water were used for irrigation as per the irrigation schedule mentioned in the treatment details (Table 2). A composite soil sample from each plot was collected at 30 DAS, 60 DAS, 90 DAS, and before treatment imposition for chemical analysis. The standard methods were followed for soil chemical properties analysis (Table 3).

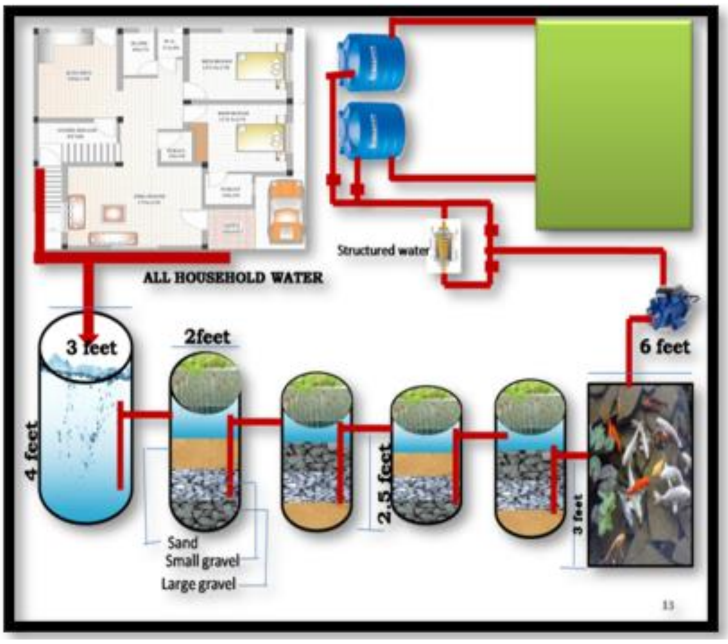

Fig. 1. Sketch of Greywater treatment unit

Fig. 2. Field established grey water treatment unit

Table 1. Chemical composition of irrigation water and method of analysi

Chemical properties	**Bore well water**	**Greywater**	**Treated greywater**	**Structured grey water**	**Method of analysis**
pH	7.00	8.53	7.53	7.42	Potentiometric method (Jackson [3]
EC (dSm^{-1})	0.29	0.87	0.44	0.43	Conductometric method (Jackson [3]
TDS (ppm)	.90.72	559.36	283.52	275.8	Condectometric method (Jackson [3]
TSS (ppm)	41.00	483.19	257.23	256.8	Filtration method (Tandon1998)
NO_3^- (ppm)	2.21	16.00	8.40	8.21	Modified Kjeldahl's method Jackson [3]
PO_4^{3-} (me / l)	0.72	3.85	1.59	1.57	Colorimetric method (Jackson [3]
SO_4^{2-} (me / l)	1.03	26.69	6.36	6.32	Turbidimetry Black [4]
K^+ (me/l)	2.12	12.47	9.64	9.61	Flame photometry (Jackson [3]
Na^+ (me/l)	2.39	52.52	32.78	31.25	Flame photometry (Jackson 1973)
Ca^{2+}(me/l)	2.10	8.93	5.34	5.25	Versenate titration method (Jackson [3]
Mg^{2+}(me/l)	1.03	4.99	2.12	2.01	Versenate titration method (Jackson [3]
CO_3^{2-} (me/l)	Nil	Nil	Nil	Nill	Titrimetric method (Hesse [5]
HCO_3^- (me/l)	3.00	26.00	10.00	9.50	Titrimetric method (Hesse [5]
Cl (me/l)	6.32	70.76	24.86	24.52	Titrimetric method (Jackson [3]
Zn (ppm)	0.14	7.34	3.18	2.69	DTPA Extractant (Lindsay and Norway 1978)
Cu (ppm)	0.02	1.13	0.15	0.23	DTPA Extractant (Lindsay and Norway 1978)
Fe (ppm)	0.51	8.60	5.02	5.01	DTPA Extractant (Lindsay and Norway 1978)
Mn (ppm)	0.08	2.58	1.25	1.26	DTPA Extractant (Lindsay and Norway 1978)
COD (ppm)	6.59	231	156.96	155.43	Open reflux method (Tandon 1998)
BOD (ppm)	2.56	48.29	31.84	31.69	Open reflux method (Tandon 1998)
SAR	1.72	14.07	12.05	11.87	-
RSC (me/l)	1.08	12.08	2.54	2.24	-
E coli	Nil	Nil	Nil	Nil	Serial dilution technique (Skinner et al.,)
Heavy metals (Cd & Cr) (ppm)	BDL	BDL	BDL	BDL	microwave digestion technique followed by ICP AES by Bordera et al. (1996)

Table 2. Treatment details

T_1	Irrigation with bore well water (control)
T_2	Irrigation with greywater
T_3	Irrigation with treated greywater
T_4	Irrigation with structured greywater
T_5	Irrigation with bore well water followed by treated greywater (alternatively)
T_6	Irrigation with bore well water followed by structured greywater (alternatively)
T_7	Irrigation with bore well water followed by treated greywater followed by structured greywater (alternatively)
T_8	Two irrigation with bore well water followed by one irrigation with treated greywater (alternatively)
T_9	Two irrigation with bore well water followed by one irrigation with structured greywater

Table 3. Initial soil properties and methods adopted for analysis

Lno.	**Soil properties**	**Values**	**Methods of analysis**
	pH	6.95	Potentiometric method (Jackson [3]
	EC(dS/m)	0.10	Conductivity bridge (Jackson [3]
	SOC(g/kg)	5.0	Wet digestion method (Jackson [3]
	Available N(kg/ha)	125.6	Alkaline $KMnO_4$ method (Jackson [3]
	Available P_2O_5	38.84	Colorimetric method (Jackson [3]
	Available K_2O	266.1	Flame photometry (Jackson [3]
	Exchangeable Ca [cmol (p+) kg^{-1}]	4.9	Versenate titration method (Jackson [3]
	Exchangeable Mg [cmol (p+) kg^{-1}]	2.1	Versenate titration method (Jackson [3]
	Available S (mg/kg)	5.3	Turbidimetry (Black 1965)
0	DTPA extracted Zn(ppm)	1.3	DTPA extraction method (Lindsay and Norwell,1978)
1	DTPA extracted Cu (ppm)	1.2	DTPA extraction method (Lindsay and Norwell,1978)
2	DTPA extracted Mn (ppm)	4.6	DTPA extraction method (Lindsay and Norwell,1978)
3	DTPA extracted Fe (ppm)	19.79	DTPA extraction method (Lindsay and Norwell,1978)
4	Urease (µg NH^{+}_4 g^{-1} soil hr^{-1})	316.01	Spectrophotometric **(**Tabatabai and Bremner, 1970**).**

Lno.	Soil properties	Values	Methods of analysis
5	Phospstase (µg PNP g^{-1} of soil hr^{-1})	16.86	Kjeldahl digestion-distillation method **(**Tabatabai and Bremner, 1970**)**.
6	Dehdrogesease (µg TPF g^{-1} of soil day^{-})	12.24	Spectrophotometric Casida et al*.* (1964)

3. RESULTS AND DISCUSSION

3.1 Effect of Domestic Greywater Irrigation on Soil pH, EC, and Soil Organic Carbon Statuss

The research data clearly indicated that the applied treatments had a significant effect on the soil reaction (pH), electrical conductivity (EC), and Organic carbon (OC) at all growth stages of the Okra crop grown (Table 4). Significantly higher pH, EC, and OC were reported in the greywater-applied plots (T_2) followed by treated greywater (T_3) and structured greywater-applied plots. It might be due to the reason that the applied greywater contained a higher quantity of sodium (52.52 me/l), calcium (8.93 me/l), magnesium (4.99 me/l) ions, and total dissolved salts (559.36 me/l), hence the resulted in the buildup of sodium, calcium magnesium ions and total dissolved salts in the soil and thus increased the soil pH and EC respectively. This way of increase in soil pH and EC with the use of greywater had been investigated by Khai et al. [6], Qishlaqi et al. [7],Misra and Sivongxay [8], Pinto et al. [9], Angin et al. [10], Rosabal et al. [11], Rodda et al. [12] and Mohamed et al. [13]. From the obtained data, it can be realized that the greywater (T_2) irrigated plots contained higher soil organic carbon at 30 DAS (5.92 g kg^{-1}), 60 DAS (6.47 g kg^{-1}), and 90DAS (6.57 g kg^{-1}) stages of Okra crop, followed by treated greywater and structured greywater irrigated plots. The reason behind the higher soil organic carbon might be due to the use of BOD, COD, and TOC-rich greywater for irrigation. The range of biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) show the organic matter status of the water. Similar works on wastewater irrigation on enhancing the soil organic carbon content were reported by Friedel et al. [14], Fuentes et al. [15], Jueschke et al. [16] and Rosabal et al. [11]. Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD0 and Total Organic Carbon(TOC) status of the treated and structured greywater got reduced during the filtering process, through the removal of carbonaceous materials by filtering materials such as sand, gravels, and activated charcoals which were used in the filtration tank. Bute et al. [17] investigated that through phytoremediation, the BOD status of the wastewater can be reduced. Hence the phytroid plant species such as cannas plant and umbrella palm used in the filtration tank might also help the reduction of the BOD status of the treated greywater. As a result, the organic carbon status of the treated and structured greywater used plots was maintained in a medium level (6.02 and 5.98 respectively). Bore well water irrigated plots recorded lower levels of soil organic carbon because bore well water does not contain carbonaceous materials.

3.2 Effect of Domestic Greywater Irrigation on Available NPK Status in the Soil

Greywater irrigated plots except where bore water alone irrigated plots recorded significantly higher available nitrogen, phosphorus, and potassium (Table 5) status of the soil at all growth stages of Okra crop. Hence

Table 4. Effect of domestic greywater irrigation on soil pH, EC, and SOC at different growth stages of Okra

Treatment details	pH (1:2.5)			EC (dSm^{-1})			SOC (g kg^{-1})		
	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS
T_1	6.94	6.92	6.87	0.11	0.12	0.15	4.94	5.24	5.21
T_2	7.22	7.83	8.43	0.23	0.38	0.47	5.92	6.47	6.57
T_3	7.08	7.15	7.61	0.19	0.27	0.36	5.75	5.95	6.02
T_4	7.07	7.14	7.53	0.18	0.26	0.34	5.73	5.91	5.98
T_5	7.03	7.05	7.23	0.16	0.17	0.29	5.44	5.64	5.71
T_6	7.02	7.04	7.21	0.15	0.17	0.27	5.42	5.62	5.69
T_7	7.09	7.13	7.51	0.16	0.18	0.28	5.47	5.68	5.74
T_8	6.97	6.99	7.05	0.13	0.15	0.23	5.27	5.41	5.59
T_9	6.96	6.97	7.03	0.13	0.14	0.22	5.26	5.35	5.56
S.Em±	0.01	0.01	0.04	0.05	0.06	0.08	0.02	0.02	0.02
CD at 5%	0.03	0.02	0.11	0.01	0.01	0.02	0.06	0.06	0.05

DAS: Days After Sowing

continuous irrigation of plots with nutrient-less bore well water resulted in leaching out of the nutrients present in the soil. In other treatments nutrient-rich greywater, treated greywater, and structured greywater were used thus the nutrients present in this water might help to maintain a higher level of nutrient status in those respective plots. The plots which received irrigation with domestic greywater (T_2) recorded higher soil available nitrogen at 30 DAS (240.58 kg ha^{-1}), 60 DAS (281.29 kg ha^{-1}), and at 90DAS (325.29 kg ha^{-1}). It was significantly different from all other treatments. The reason behind the elevation was the use of nitrate-loaded greywater. A similar type of work had been reported by Khai et al. [6], Adrover et al. [18] and Pandey et al. [19] reported that the wastewater application had a positive effect on the soil available nitrogen, with the wastewater application of the soil available nitrogen increased from 12.4 to 27.1 kg ha^{-1}Plots received grey water alone (T_2) recorded significantly higher available phosphorous at 30 DAS (78.15 kg/ha), 60 DAS(89.54 kg/ha) and 90 DAS (105.67 kg/ha) respectively as compared to other types of water used in irrigation. Greywater was having a higher concentration of phosphate phosphorous (3.85 me/l) as compared to treated greywater (1.59 me/l), structured greywater (1.57 me/l), and bore well water which was used for irrigation; hence greywater direct application correspondingly improved the soil available phosphorus status. Analogous works had been conducted by Rana et al. [20], Pinto et al .[19]and Mohamed et al. (2013) and they also concluded that continuous use of greywater resulted in an increase in soil available phosphorous. Soil available potassium status was recorded significantly higher in the greywater alone (T_2) used plots at 30 DAS (317.56 kg/ha), 60 DAS (421.84kg/ha), and 90 DAS (499.53kg/ha) as compared to structured water and treated greywater used plots, because the used treated greywater and structured greywater was having less potassium status than that of the greywater alone (T_2). It may be due to the reason that when the greywater passed through the filtrations tank then the positively charged potassium ions may get fixed on the negatively charged site of the filtering materials such as charcoals. Also, the umbrella palms (monocot plant) used in the filtration tank has the capacity to take up more amount of monovalent potassium ion, as explained by Drake et al. [21].

3.3 Effect of Domestic Greywater Irrigation on Available Sulphur, Exchangeable Ca and Mg Status in the Soil

A significantly higher level of sulfur was recorded in plots that received greywater treatment (T_2) at 30 DAS (9.77 mg kg^{-1}), 60 DAS (11.93 mg kg^{-1}), and 90 DAS (20.19 mg kg^{-1}). Greywater used for irrigation contained a higher amount of sulfate sulfur (26.69 me/l) and this was the reason for the enhancement of the sulfur level in greywater irrigated plots. A similar observation was recorded by Abegunrin et al. [22]. The plots which received alternate irrigation with treated or structured greywater and bore well water recorded comparatively lower sulfate sulfur, because the freshwater might have washed out the sulfate form of sulfur from the top layer and maintained a lower sulfur status in the treated plots. The level of sulfate sulfur present in the treated greywater gets reduced compared to the greywater due to the action of phytroid plant species that were grown in the filtration tank. They may effectively take up the major part of sulfate sulfur present in the greywater. Similar findings were reported by Bute et al. [17], who observed that the phytroid plants grown in the filtration tank could reduce the sulfate sulfur concentration of the wastewater from 70 me/l to 62 me / l.

The greywater irrigated plots in these experiments were loaded with higher amounts of calcium and magnesium at all growth stages of crop (Table 6). Plots that received greywater alone (T_2), recorded significantly higher calcium (8.57,9.39 and 11.57 cmol (p+) kg^{-1}) and magnesium 4.27,4.67 and 4.99 cmol (p+) kg^{-1}) at 30DAS,60 DAS and at 90DAS respectively. Lower calcium and magnesium contents were found in bore well water received plots. Household greywater contained higher levels of calcium and magnesium ions; hence its direct use in the field resulted in enhanced exchangeable calcium and magnesium. Similar findings had been reported by Qishlaqi et al. (2008); Rana et al. [20] and Abegunrin et al. (2016). When the greywater passes through different filtration tank, the positively charged calcium and magnesium ions might get fixed on the exchange site of the filtering material, as a result, the concentration of these ions get reduced in the treated greywater and structured greywater. These may be the reason for the lower status of the exchangeable calcium and magnesium in the treated and structured

Table 5. Effect of domestic greywater irrigation on soil available N, P_2O_5 and K_2O status

Treatment	N (kg ha^{-1})			P_2O_5 (kg ha^{-1})			K_2O (kg ha^{-1})		
	30 DAS	**60 DAS**	**90DAS**	**30 DAS**	**60 DAS**	**90DAS**	**30 DAS**	**60 DAS**	**90DAS**
T_1	135.96	147.50	127.42	38.03	47.08	49.61	264.32	275.40	286.71
T_2	240.58	281.29	325.29	78.15	89.54	105.67	317.56	421.84	449.53
T_3	219.12	229.63	242.34	65.99	73.66	81.43	299.86	325.71	344.23
T_4	217.85	228.25	240.69	64.46	72.72	80.86	297.95	324.85	342.67
T_5	160.76	178.91	192.90	51.29	64.91	72.78	275.03	298.75	320.21
T_6	159.75	177.99	191.49	50.85	63.99	72.49	274.72	297.99	319.51
T_7	161.31	179.01	193.11	52.01	65.05	73.00	276.91	299.02	321.13
T_8	150.29	156.58	161.18	42.95	51.97	60.88	268.52	285.07	307.21
T_9	148.71	155.31	161.02	44.53	51.05	60.43	268.55	284.25	305.64
S.Em±	**0.81**	**0.50**	**0.56**	**0.73**	**0.37**	**0.21**	**0.85**	**0.36**	**0.59**
CD at 5%	**2.45**	**1.50**	**1.67**	**2.18**	**1.12**	**0.64**	**2.55**	**1.08**	**1.78**

Table 6. Effect of domestic greywater irrigation on soil exch. Ca, Mg and available S

Treatment details	Exchangeable Ca			Exchangeable Mg			Available S		
	cmol (p+) kg^{-1}						mg kg^{-1}		
	30 DAS	**60 DAS**	**90DAS**	**30 DAS**	**60 DAS**	**90DAS**	**30 DAS**	**60 DAS**	**90DAS**
T_1	4.48	4.53	4.59	1.57	1.87	1.80	2.83	2.97	2.96
T_2	8.57	9.39	11.57	4.27	4.67	4.99	9.77	11.93	20.19
T_3	5.66	5.94	6.32	3.55	3.87	4.24	4.88	5.52	10.86
T_4	5.48	5.87	6.30	3.48	3.81	4.18	4.80	5.55	10.79
T_5	4.85	5.15	5.37	2.96	3.53	3.90	4.04	4.55	8.91
T_6	4.74	5.08	5.35	2.93	3.49	3.85	3.98	4.46	8.89
T_7	5.25	5.37	5.63	3.16	3.64	4.08	4.06	4.51	9.00
T_8	4.27	4.83	5.17	2.61	2.97	3.63	2.59	3.38	6.05
T_9	4.15	4.79	5.10	2.53	2.94	3.57	2.65	3.59	5.98
S.Em±	**0.12**	**0.03**	**0.07**	**0.04**	**0.03**	**0.06**	**0.03**	**0.09**	**0.04**
CD at 5%	**0.35**	**0.08**	**0.19**	**0.11**	**0.08**	**0.15**	**0.09**	**0.26**	**0.12**

Table 7. Effect of domestic greywater irrigation on soil DTPA – extracted micronutrients status

Treatment details	Fe			Cu			Zn			Mn		
	mg kg^{-1}											
	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS
T_1	14.69	14.74	14.88	1.34	1.53	1.64	1.66	1.69	1.71	4.37	4.40	4.41
T_2	31.73	35.67	40.53	2.18	2.77	3.10	2.72	3.91	4.26	8.25	13.37	21.57
T_3	27.89	30.95	34.95	2.09	2.38	2.52	2.42	3.17	3.38	6.93	12.73	18.92
T_4	27.83	30.67	34.84	2.07	2.35	2.53	2.40	3.15	3.33	6.90	12.61	18.87
T_5	23.77	27.82	30.44	1.96	2.08	2.22	2.06	2.74	2.96	4.91	11.21	16.81
T_6	23.63	27.64	30.37	1.95	2.05	2.15	2.05	2.72	2.87	4.88	11.09	16.69
T_7	23.96	28.01	30.48	1.98	2.10	2.28	2.35	2.97	3.19	5.26	11.78	17.65
T_8	16.85	19.37	21.07	1.69	1.96	2.02	1.97	2.56	2.69	4.22	7.85	13.64
T_9	16.53	19.19	20.87	1.66	1.91	1.95	1.95	2.54	2.70	4.19	4.40	13.59
S.Em±	**0.12**	**0.14**	**0.09**	**0.09**	**0.02**	**0.05**	**0.01**	**0.02**	**0.05**	**0.02**	**0.06**	**0.05**
CD at 5%	**0.36**	**0.43**	**0.29**	**0.04**	**0.06**	**0.15**	**0.02**	**0.03**	**0.15**	**0.04**	**0.17**	**0.14**

Table 8. Effect of domestic greywater irrigation on soil enzymatic activities

Treatment details	Dehydrogenase (μg TPF g^{-1} of soil day^{-1})			Urease (μg NH_4^+ g^{-1} soil hr^{-1})			Phosphatase (PNP g^{-1} soil hr^{-1})		
	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS	30 DAS	60 DAS	90DAS
T_1	15.80	16.53	16.92	324.68	324.92	325.11	17.49	17.86	18.44
T_2	28.72	32.59	35.87	351.39	355.60	359.07	31.73	35.89	39.47
T_3	23.94	28.15	31.55	343.67	347.84	351.67	27.24	31.29	35.21
T_4	23.43	27.52	30.19	342.58	346.77	350.56	26.86	30.78	34.80
T_5	20.76	24.72	27.50	340.77	344.59	348.78	22.63	26.77	29.53
T_6	20.33	24.41	27.28	340.18	344.22	347.81	22.15	26.38	29.06
T_7	21.29	25.04	27.92	341.05	345.25	348.91	22.04	26.92	29.63
T_8	18.77	23.17	26.25	337.48	341.63	344.50	20.15	24.37	26.58
T_9	18.14	22.79	25.38	336.72	340.90	343.88	19.87	23.89	26.16
S.Em±	**0.35**	**0.25**	**0.55**	**0.41**	**0.43**	**0.51**	**0.21**	**0.23**	**0.23**
CD at 5%	**1.05**	**0.75**	**1.64**	**1.24**	**1.29**	**1.54**	**0.62**	**0.68**	**0.67**

greywater received plots as similar findings reported by Bute et al. [17].

3.4 Effect of Domestic Greywater Irrigation on Micronutrients (Zn, Cu, Fe, and Mn) Status in the Soil

The data on, the use of domestic greywater irrigation on the cultivation of the Okra crop significantly influenced micronutrient the status of soil (Table 7). DTPA-extracted zinc, copper, iron, and manganese micronutrients concentration were higher in soil which plots were irrigated with greywater alone (T_2) followed by treated greywater (T_3) and structured greywater (T_4) at all three stages of crop growth. As the greywater contains a higher amount of zinc (7.34 me/l), iron (8.60 me/l), copper (1.13 me/l) and manganese (2.58 me/l), then its direct application may lead to increase in soil micronutrients concentrations. Chang et al. (1984); Liu et al. (2005) and Faryal et al. (2007) were reported that changes occur in the available micro nutrient status in soil upon the application of waste water.

3.5 Effect of Domestic Greywater Irrigation on Activities of Dehydrogenase, Phosphatase, and Urease Enzymes

It was found that the household grey water applied plots were having a significant effect on the enzyme activities compared to bore water irrigated plots (Table 8). Significantly higher activities of dehydrogenase were recorded from the plots which received greywater irrigation alone (T_2) at 30 DAS (28.72µg TPF g^{-1} of soil day^{-1}),60 DAS (32.59 µg TPF g^{-1} of soil day^{-1}) and at 90 DAS (35.87µg TPF g^{-1} of soil day^{-1}) respectively. Dehydrogenase is an extracellular enzyme that enhances the mineralization process of organic matter. As the organic matter content increase in the soil, it results in increased dehydrogenase activities (Adak et al., 2014) Orenes et al. [23] investigated the long-term effect of irrigation of the agriculture plots with wastewater, which showed significantly increased soil dehydrogenase activities in applied plots. Similar findings were also reported by Adrover et al. [18] and Baddam et al. (2016) [24].

From the results of the experiment, it was found that irrigation with grey water significantly influenced the activities of the phosphatase enzyme also. The plots irrigated with greywater alone showed significantly higher phosphatase activity at 30DAS (31.73 PNP g^{-1} soil hr^{-1}), 60DAS (35.89 PNP g^{-1} soil hr^{-1}), and at 90DAS (39.21PNP g^{-1} soil hr^{-1}) respectively. This enzyme acts on the complex phosphorous compounds and converts them into available forms. Greywater originating from households, especially laundry water usually contains a higher amount of complex phosphorous compounds [25]. So this type of greywater used in the plots may increase the concentration of complex phosphorous compounds. This may be the reason for the increased activity of the phosphate in the greywater applied plots more than the other treatment.

With the application of greywater in the soil the urease enzyme activities were enhanced at different growth stages of the tested crop (Table 8). The plots irrigated with greywater alone recorded significantly higher urease activity at 30DAS (351.39 µg NH_4^+ g^{-1} soil hr^{-1}), 60DAS (355.60 µg NH_4^+ g^{-1} soil hr^{-1} and at 90DAS (359.07 µg NH_4^+ g^{-1} soil hr^{-1}) respectively. The increased amount of nitrogen compound present in the greywater results in lifted nitrogen content in the soil this can be the reason for the enhanced urease enzyme activity in the soil. This observation is confirmed by the findings of Brzezinska et al. (2006) [26] and Kayikcioglu [27].

4. CONCLUSION

From this experiment, it can be concluded that the direct use of the generated domestic greywater significantly changed the soil physio-chemical and biological properties. In treated and structured greywater used plots also significant changes were found but those were significantly lower than that of the greywater alone received plots. Greywater received plots recorded higher nutrient status in the present study. So, it can be concluded that in the present study, the safe use with minimum treatment with low-cost irrigation with greywater helps to improve the nutrient status, especially macro and micronutrients, and enzymatic activities. But increase in the soil pH was noted in the greywater-applied plots so this may harm the long-term use of greywater in the plots. So the soil which faces the problems of salinity there we can use treated greywater. Any way to vanquish the water crises in the agriculture sector safe use with the minimum treatment of domestic greywater reuse is the best option to increase agricultural production in future days specific to the peri-urban agriculture sector across the world to meet the food demand of the ever-growing population.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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