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USE OF AQUATIC PLANTS FOR TREATMENT OF GREYWATER

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Abstract

Some aquatic plants have the ability to treat the water there by improving its quality. The main objectives of the study were to introduce the greywater treatment using local plants and secondly to assess its quality for agricultural use. In this regard, vertical flow subsurface constructed wetland units were operated to treat greywater of residential area of Sindh Agriculture University, Tandojam using three types of plants i.e. *Cyperus iria, Phragmites karka* and *Typha elephantina*. Water samples were collected before and after their treatment with each plant. pH and BOD values decreased from 8.32 and 402 mg L^{-1} in untreated greywater to a minimum of 7.46 and 48 mg L^{-1} respectively in the one treated by *Phragmites karka*. The plant species were not effective with regard to EC, TDS and TSS. After recycling, the NO_3-N contents remained more or less same, which was the major form of nitrogen in greywater samples, however, it reduced in *Cyperus iria* and phosphorus in addition to *Cyperus iria* was recycled under *Typha elephantina.* Potassium contents in all the cases were more or less similar and increased to small extent. It was concluded that greywater contains significant quantities of nitrogen, phosphorus and potassium and can be used as a value added fertilizer in agriculture. *Phragmites karka* was effective in reducing pH, BOD and Cyperus iria in NO_3-N. The increase in salt content of treated water may be due to the salt content of soil itself used in reed beds which can be avoided by using soil with low salt content.

Key words: Constructed wetlands, greywater, recycling, quality of irrigation water

Introduction

Shortage of freshwater resources is a worldwide dilemma and its unavailability for agricultural irrigation is the basic limiting factor in food production with no exception to Pakistan. It is anticipated that the population of Pakistan may increase to 208 million by 2025 (Sheikh *et al*., 2005) and ultimately increase the wastewater generation. An alternative to this solution is to recycle and reuse the generated wastewater. Part of wastewater is greywater, which is the water from whole house but the toilet and typically 50-80% of the household wastewater is greywater (Eriksson *et al*., 2003; Friedler & Hadari, 2006). Generally, the N, P and K contents and pathogen levels related to health are low in greywater which is further minimized when greywater is recycled (Jenssen & Vråle, 2004). Domestic wastewater is a good source of fertilizer for plants; it is also a source of environmental pollution and a medium where different microorganisms hazardous to human health can exist unless recycled.

Among many wastewater treatment systems, reed-bed is a physical man made constructed wetland system, planted with different aquatic plants belonging to different species. These systems are low-cost, longer-lasting and environment friendly (Anon., 2004). Introduction of wetland systems in a developing country like Pakistan can bring a significant change in the livelihood of local people due to partial substitution of fertilizer input and irrigation water cost. The system can be designed nearby gardens or crop fields to have direct excess of treated water. Wetland systems are efficient in reducing biological oxygen demand (BOD), nitrogen, phosphorus and total solids (TS) i.e. total suspended solids (TSS) and total dissolved solids (TDS) up to 98% (Denny, 1997). Greywater, after its proper treatment has been successfully used on agricultural crops in Jordan (Al-Hamaiedeh & Bino, 2010), Thailand (Konnerup *et al*., 2009; Perbankhem & Polprasert, 2010), Nepal (Bista & Khatiwada, 2004), USA (Hench *et al*., 2003), Canada (Zurita *et al*., 2009), Denmark (Brix & Arias, 2005), Portugal (Calheiros *et al*., 2009) and many other places. Results of these studies show that contamination levels are generally low for many crops and do not represent a significant health risk. Plant growth and productivity are not affected by water quality, owing to the low N, P and K levels of the greywater. These results reinforce the potential of domestic greywater as an alternative for irrigation. Similar results have been reported by Friedler (2004) and Surendran & Wheatley (1998) for reuse of shower and laundry water for irrigation. Misra & Sivongxay (2009) reported that greywater was significantly more alkaline and more saline then the tap water. He concluded that greywater irrigated plants had the highest concentration of P. The results suggested that if plants are managed well to maintain growth, the selected plant is able to remove pollutant from greywater irrigated soils without being adversely affected by surfactant residues and other pollutants in water.

Wastewater treatment using constructed wetlands is not a common practice in Pakistan and yet the greywater treatment. In this connection, few studies locally designed have introduced the wetland systems in the country using wastewater from oil refinery, Rawalpindi (Aslam *et al*., 2007), Sewer water of University of Engineering and Technology, Lahore (Hayder *et al*., 2015) and wastewater of Nadirshaw Eduljee Dinshaw (NED) University of Engineering and Technology, Karachi (Mustafa, 2013). These studies however, have not drawn a clear line to separate greywater from domestic or even wastewater from other sources. So far, there is no local research on the record showing treatment of greywater alone and yet in the rural areas of Sindh province of Pakistan. This study aims to introduce the treatment of greywater through constructed wetlands technology using greywater of Sindh Agriculture University Colony, Tandojam and secondly, to evaluate the greywater quality for irrigation on agricultural crops.

Materials and Methods

The study of greywater treatment growing aquatic plants using reed-bed technology was carried out at residential area of Sindh Agriculture University, Tandojam occurring at 25^o 25’ 35.68” N and 68’ 22.31” E in a arid/semi-arid sub-tropical climate with average rain fall of 150-200 mm and maximum average temperature of 40^{o}C (FAO, 2001). The treatment scheme consisted of a 9.1 m^2 cemented tank attached with a motor pump, a 240 L cylindrical plastic tank and 6 vertical flow subsurface constructed reed-bed units (Fig. 1) each with the dimensions of 2x1x1 m (length x width x depth) in addition to domestic wastewater from ten houses. The units were packed at 0.7 m depth, using mixed material i.e. sand (42.5%), silt (35.5%), clay (22.5% and farm yard manure having electrical conductivity and pH of 3.65 dS m^{-1} and 8.33, respectively. Each of the three reed-bed units were used to grow the locally collected aquatic plants *Cyperus iria* (sedge grass), *Phragmites karka* (reed grass) and *Typha elephantina* (reed mace), locally termed as Kull, Nurr and Pann, respectively. The greywater from ten houses, each through a separate pipe was discharged into main tank and was pumped into cylindrical plastic tank (attached with treatment units) when required. The treatment units were supplied with greywater from plastic tank via PVC pipes (1.5" diameter) having T-shape inlet valves.

The treatment of greywater began to operate in the month of April and the system was stabilized during May and June. However, owing to heavy rains in the month of June, largest part of the district was flooded creating operation difficulties in the system. Thereby, the system was stabilized again for a month by continuously applying untreated greywater, followed by 2 months operation and monitoring of some parameters. A measured quantity of greywater (30L 43 Sec^{-1}) was discharged from the plastic tank into treatment units three times a day at an equal interval (8 hours) time discharging total 90L day^{-1}, continued for one month period. Sampling was carried out between 8 and 9 am on daily basis for a period of one month during October. Untreated greywater from the main tank and the treated one from outlet ports of each *Cyperus iria*, *Phragmites karka* and *Typha elephantina* treatment units was collected in autoclaved 500 ml sample bottles and packed on ice in insulated coolers for transport to the laboratory (Shaheen *et al*., 2016).

Quality of treated and untraded greywater was tested by standard methods. Electrical conductivity (EC) and pH were simply measured by using EC (HI 8033) and pH (WTW-720) meters after their proper calibration using standard 0.02M KCl and buffer (7.0 and 9.0) solutions, respectively. Biological oxygen demand (BOD) and total solids (TS) (TDS+TSS) were analyzed as given in the Anon. (1998) for waste water determination. BOD represents the amount of oxygen required to completely oxidize the organic matter present in a sample. It was determined by incubating the sample into BOD bottles for 5 days at 20^{o}C after proper preparation of the sample including dilution water. Dissolved oxygen was measured before and after the incubation and BOD was computed from the difference. TSS and TDS were separately measured by using filter (0.45um) and evaporation (100^{o}C) methods, respectively and summed to give TS. The nitrogen forms (NH_4-N and NO_3-N) were analyzed as outlined by Tandon (2005), soluble phosphorus by developing a blue colored complex (Murphy & Riley, 1962), followed by quantitative determination on spectrophotometer and potassium by emission spectroscopy (Knudsen *et al.,* 1982) using flame photometer.

Descriptive statistics in the form of minimum, maximum, mean, mode, standard deviation, and analysis of variance, and linear regressions were used to analyze the data using SAS/STAT Software (Anon., 2001).

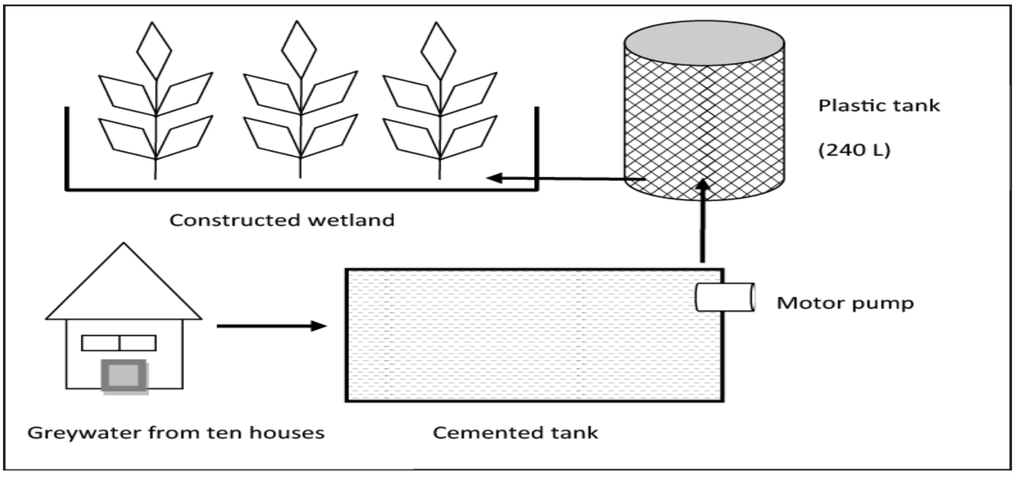

Fig. 1. Schematic diagram of the experimental setup

Results and Discussion

Physical quality of greywater: All the samples of greywater before their treatment had a bit foul odor and very light grayish color. The same water after treatment was clear and had no intolerable odor. Out of 270 samples of greywater collected after the treatment, each from *Cyperus iria*, *Phragmites karka* and *Typha elephantina*, 255 samples had TDS values within "slight to moderate" category (450-2000 mg L^{-1}). The remaining 15 samples treated through *Phragmites karka* were above 2000 mg L^{-1} falling under "severe" category (Ayers & Westcot, 1985). The TSS values were very minor part (0.02 to 0.41 mg L^{-1}), of total solids compared to TDS. On comparative basis, the untreated greywater had lower TDS (1276 -1574 mg L^{-1}) and TSS (0.03-0.04 mg L^{-1}) values. The EC values of the greywater water samples ranged from 2.14 to 5.43 mg L^{-1} (Table 1). As per criteria given by Ayers & Westcot (1985), the EC data show that 100% samples, each by *Cyperus iria* and *Typha elephantina* were within the "slight to moderate" category (0.70-3.0 dS m^{-1}). While, all the samples (100%) treated with *Phragmites karka* were above the DRI limit of 3.0 dS m^{-1} falling under "severe" category (Table 2). The greywater before its treatment also had significant quantities of soluble salts but had relatively lower EC (2.05-2.51 dS m^{-1}) values than the treated samples. The TDS, TSS and EC values of untreated greywater of Islamabad city, Pakistan as reported by Sehar *et al*. (2013) were 480 mg L^{-1}, 478 mg L^{-1} and 0.51 dS m^{-1} respectively. These values continued to increase from 4 to 16 HRT (hydraulic retention time) (days), but decreased at 20 HRT (days). Another local study (Pathan, 2011) on greywater treatment (rotating biological contractor) reported, relatively higher TSS and lower TDS values, however, after treatment, a small decrease (154.63 to 140.75 mg L^{-1}) in TSS and increase in TDS (6.23 to 6.48 mg L^{-1}) was observed. On the other hand, the work by Finley *et al*., (2009) recorded an increase in TS from 313 to 330 mg L^{-1}. Generally, greywater has much lower TSS values (21-250 mg L^{-1}) in contrast to the values reported for other types of wastewater i.e. municipal (100-360 mg L^{-1}) (Siegrist, 1977) or university campus water (45 mg L^{-1}) having laboratory wastage in the form of chemicals (Mustafa, 2013). Other studies (Vipat *et al*., 2008; Dhote & Dixit, 2009; Dhulap & Patil, 2014) show a decrease in TDS, TSS and EC values of greywater after its treatment. The salt content of untreated greywater may vary even within same region, depending on the usage practices in that area. Similarly, the treated greywater depends not only on the original values of untreated water but on the type of reed-bed mixture. None of the studies mentioned here have used a saline reed-bed mixture. Conversely, the increase in TDS, TSS and EC of treated greywater in this study may be attributed to the high salt content of reed-bed mixture itself having EC value of 5.0 dS m^{-1}, whereas mean EC of the untreated greywater of residential colony was about half of that (2.36 dS m^{-1}) ranging between 2.05 and 2.65 dS m^{-1}. Observing the EC values in relative context, the treatment has actually decreased TDS, TSS and EC values of greywater.

Chemical quality of greywater: The pH values of treated greywater ranged between 7.38 and 8.28. As per criteria given by Ayers & Westcot (1985) for water quality for agriculture, 100% samples treated through *Phragmites karka*, 60% by *Typha elephantina* and 8% by *Cyperus iria* were in normal range of 6.5-8.0. The remaining 30% samples by *Typha elephantina* and 82% by *Cyperus iria* had pH above DRI limit of 8.0. According to Anon., (2005) for municipal and liquid industrial effluents of Pakistan, pH of all the greywater samples was within prescribed range of 6-9. The pH values of untreated greywater were much higher (8.18-8.46) compared to the treated ones (Table 1). Among three aquatic plants grown under reed-bed technology, *Phragmites karka* was most effective in reducing pH by 10.3%, followed by *Typha elephantina* (4.2%) and *Cyperus iria* (2.6%) (Fig. 2a). pH decrease in treated greywater with *Phragmites karka* has been reported by Choudhary *et al*. (2011). Similar results were reported by Hench *et al*. (2003) for the domestic wastewater of Morgantown, Monongalia, West Virginia, USA using a mixture of *Typha scirpus* and *Juncus* species. The type and quantity of detergents used has direct effect on the pH values of greywater. Detergents are generally alkaline in nature with pH above 10 (Zavala and Estrada, 2016). The pH of treated greywater and even the untreated one in this study is way below 10 and therefore its usage as irrigation water in agriculture cannot harm many plants or organisms. Iram *et al*., (2012) reported similar pH values of 6.8-7.7 for bio-treatment ponds functioning at National Agricultural Center, Islamabad.

Among two available forms of nitrogen (NH_4-N and NO_3-N), the later was the major form (7.49-19.39 mg L^{-1}) present in treated greywater samples with little higher contents (13.42-15.19 mg L^{-1}) in untreated one (Table 1). The data in Table 2 shows that all the samples were within the DRI range of 5.0-30.0 mg L^{-1} categorized as "slight to moderate" (Ayers & Westcot, 1985). Considering the treatment by plant species, *Cyperus iria* was the only specie reducing average NO_3-N contents from 14.17 to 13.41 mg L^{-1} with 5.4% recycling (Fig. 2b). Pidou *et al*. (2008) also reported NO_3-N content as major form of nitrogen in treated greywater samples of Granfield University in UK by using different treatment processes. Hench *et al*. (2003) found 74, 31 and 13 % Kjeldahl's N removal in three consecutive years, respectively. In greywater treatment by reeds, nitrification and denitrification are the main processes of N conversion (Kadlec & Wallace, 2009). Song *et al*. (2006) reported 47% reduction in NH_4-N. In contrast, this study reported very low loads of NH_4-N in untreated greywater, demonstrating conversion of NH_4-N to NO_3-N form, followed by only 5.7% removal by *Cyperus iria*. The low removal efficiency or none by other aquatic plants may be due to the net rate of biomass buildup, and its withdrawal from the system which should be less than the growth rate of the nitrifying bacteria (Barnes & Bliss, 1983).

Soluble phosphorus of untreated greywater ranged from 0.46-0.92 mg L^{-1}. In contrast, the treated greywater ranged from 0.02-1.00 mg L^{-1} with maximum values by

Phragmites karka (0.81 mg L^{-1}), followed by *Cyperus iria* (0.58 mg L^{-1}) and *Typha elephantina* (0.38 mg L^{-1}) (Table 1). On percent basis, soluble phosphorus was maximum treated by *Typha elephantina* (44.1%) and minimum by *Cyperus iria* (14.7%) (Fig. 2c). No prescribed limits are defined for phosphorus in the irrigation water by Ayers & Westcot (1985) & Pescod (1992). However, according to UN Department of Technical Cooperation for Development (Anon., 1985), the phosphorus content of all the samples was <6 mg L^{-1} categorized as "weak domestic" wastewater. Phosphorus values reported for residential colony, SAU, Tandojam are much lower compared to those reported for the wastewater from NED University campus and staff colony, ranging between 4.5 to 10.2 mg L^{-1} with average removal of 52% (Mustafa, 2013). The lower content of phosphorus in this study may be due to the reason that there was no wastewater coming from research laboratories containing chemical compounds, also the lower proportion of clay particles. Soluble P content of treated wastewater as reported under literature varies from 1.4 to 14.5 mg L^{-1} (Lowe *et al*., 2007; May *et al*., 2014; Ockenden *et al*., 2014). On the other hand, the treatment performance concerning the phosphorus removal quantities from greywater are not satisfactory. The main phosphorus removal processes in reed beds are similar to phosphorus fixation in soils, including precipitation of P as Ca/Fe-phosphates and sorption with $CaCO_3$, Al and Fe oxides and hydroxides (Memon *et al*., 2011). The proportion of clay and organic matter content in the reed-bed mixture can influence the removal performance i.e. as the presence of negatively charges sites (clay and humus) is directly proportional to phosphorus removal quantity (Beal *et al*., 2005; Memon *et al*., 2011). Consequently, the phosphorus removal in these systems can be easily increased (Eveborn *et al*., 2014).

Soluble potassium contents of treated greywater ranged between 47.0 and 97.0 mg L^{-1} with mean maximum values in *Phragmites karka* (80.7 mg L^{-1}) and minimum in *Cyperus iria* (65.6 mg L^{-1}). Relatively, the potassium content of untreated greywater was slightly lower, ranging between 38.0 and 91.0 mg L^{-1} (mean 60.0 mg L^{-1}) presenting no reduction in potassium content after treatment. As potassium is part of salt present in water, it is already included in the form of EC. Owing to this, none of greywater treatment studies have included potassium as an individual parameter. The amount of potassium content in irrigation water is important as it is major essential nutrient required for crop growth and quality production. Future studies should follow the use of treated greywater on crops and its evaluation with regard to plant uptake to take decisions on the quantum of irrigation.

Table 1. Quality of treated and untreated greywater in the form of range, mean ±standard deviation and coefficient of variability.

Parameters	**Untreated greywater**	**Treated greywater**		
		Cyperus iria	***Phragmites karka***	***Typha elephantina***
TDS (mg L^{-1})	1276-1574	1330-1568	1535-2497	1423-1677
	1421±69.9	1442±54.1	1999±359.3	1546±65.7
	4.9	3.7	18.0	4.3
TSS (mg L^{-1})	0.03-0.04	0.02-0.08	0.15-0.41	0.03-0.09
	0.03±0.01	0.05±0.03	0.28±0.13	0.06±0.03
	0.03	0.02	0.15	0.03
EC (dS m^{-1})	2.05-2.51	2.14-2.58	3.65-5.43	2.28-2.70
	2.28±0.11	2.35±0.11	4.42±0.60	2.49±0.10
	2.15	-	5.13	2.52
pH	8.18-8.46	7.94-8.28	7.38-7.55	7.45-8.19
	8.32±0.09	8.11±0.09	7.46±0.05	7.97±0.14
	8.36	8.05	7.44	8.06
NH_4-N (mg L^{-1})	1.29-3.68	3.13-5.95	1.29-3.99	1.69-5.45
	2.71±0.84	4.14±0.61	2.85+0.72	3.75±0.91
	3.65	4.39	1.99	3.99
NO_3-N (mg L^{-1})	13.42-15.19	7.49-18.83	13.49-18.99	13.64-19.39
	14.17±0.50	13.41±3.46	15.59±1.68	15.98±1.44
	14.97	16.96	15.10	16.99
Soluble P (mg L^{-1})	0.46-0.92	0.02-1.00	0.49-1.00	0.12-0.94
	0.68±0.09	0.58±0.25	0.81±0.15	0.38±0.17
	0.74	0.62	0.91	0.36
Soluble K (mg L^{-1})	38.0-91.0	48.9-78.2	54.6-97.0	47.0-91.2
	60.0+15.0	65.6±7.4	80.7±12.9	69.4+11.7
	52	68.0	90.9	-
BOD (mg L^{-1})	374-433	118-263	06-96	128-185
	402±16	190±52	48±29	154±14
	402	231	66	148

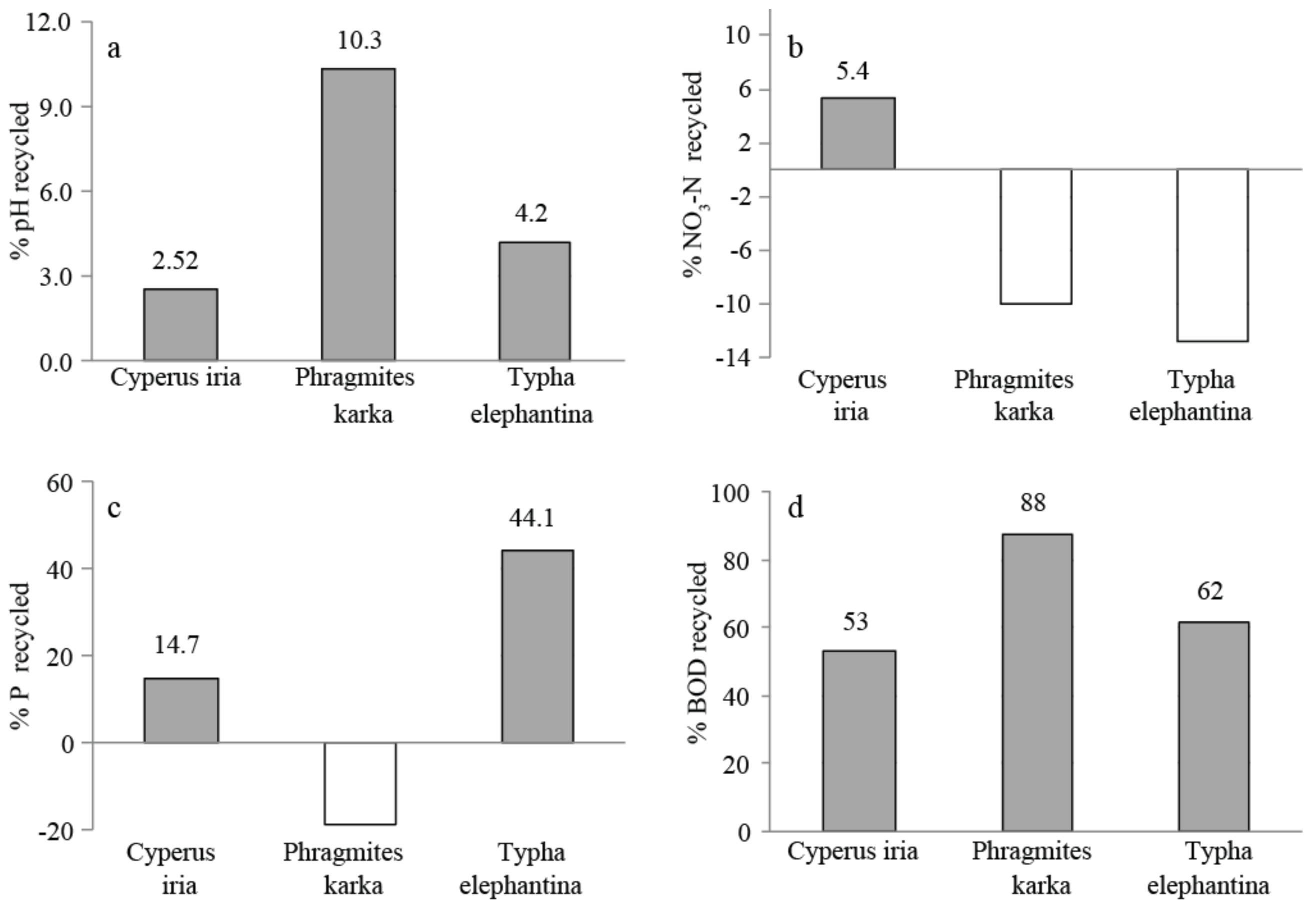

Fig. 2. Percent recycling of greywater for (a) pH (b) NO_3-N (c) P and (d) BOD by each *Cyperus iria*, *Phragmites karka* and *Typha elephantina* over the untreated one.

Table 2. Percent distribution of treated greywater properties under *Cyperus iria*, *Phragmites karka* and *Typha elephantine.*

Parameter	Degree of restriction for irrigation (DRI)								
	None			Slight to moderate			Severe		
	CI	PK	TE	CI	PK	TE	CI	PK	TE
TDS		<450			450-2000			>2000	
(mg L^{-1})	0(0)	0(0)	0(0)	90(100)	75(83)	90(100)	0(0)	15(17)	0(0)
EC		<0.7			0.7-3.0			>3.0	
(dS m^{-1})	0 (0)	0(0)	0(0)	90(100)	0(0)	90(100)	0(0)	90(100)	0(0)
pH		<6.5			6.5-8.0 (normal range)			>8.0	
	0(0)	0(0)	0(0)	10(11)	90(100)	45(50)	80(89)	0(0)	45(50)
NO_3-N		<5.0			5.0-30.0			>30.0	
(mg L^{-1})	0(0)	0(0)	0(0)	90(100)	90(100)	90(100)	0(0)	0(0)	0(0)
								>20	
Soluble P		<6.0			10-20				
(mg L^{-1})	90(100)	90(100)	90(100)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
					-				
BOD_5		<80						>80	
(mg L^{-1})	0(0)	82(91)	0(0)	-	-	-	90(100)	8(9)	90(100)

Note: - The values underlined are the critical limits of the given parameter as given by Ayers & Westcot (1985), except for soluble P (UN Department of Technical Cooperation for Development (1985) and BOD (NEQS, 1997).

- The values outside and in parenthesis denote number and percent samples respectively
- CI *Cyperus iria*; PK - *Phragmites karka*; TE - *Typha elephantina*

Conclusions

Biological oxygen demand (BOD): The untreated greywater had high values of BOD (374-433 mg L^{-1}) with mean values of 402 mg L^{-1}. After treatment, the values decreased tremendously with lowest mean values of 48 mg L^{-1} by *Phragmites karka*, 154 mg L^{-1} by *Typha elephantina* and 190 mg L^{-1} by *Cyperus iria* (Table 1), achieving highest BOD removal by *Phragmites karka* (88%) and lowest by *Cyperus iria* (53%) (Fig. 2d). There are no clear DRI limits on BOD for treated greywater or even for general irrigation purposes. According to Anon., (1997) for municipal and liquid industrial effluents of Pakistan, if utilized for land water, the BOD values should not exceed 80 mg L^{-1}. Considering that, majority of the samples (91%) recycled under *Phragmites karka* were below the DRI limit and fit for irrigation to agricultural crops. Conversely, 100% samples each by *Cyperus iria* and *Typha elephantina* had BOD above the DRI ($\geq$80 mg L^{-1}) limit (Table 2). In reality, the BOD values are not restricted; it rather depends on the type of soil or crop grown. According to UN Department of Technical Cooperation for Development (Anon., 1985), the domestic wastewater having BOD of 200 and 100 mg L^{-1} is considered as "Medium" and "Week" respectively, in BOD concentration. According to literature the BOD percent removal of wastewater is between 60 and 85 % (Seabloom & Hanson, 2005 & Tayade *et al*., 2005). This study reports 88% BOD removal with *Phragmites karka* which is exactly in line with the BOD removal (73%) reported by Hayder *et al*., (2015) for the wastewater of Lahore city, Pakistan under reed-bed technology using *Phragmites karka*. Other studies by Zurita *et al*., (2009) and Vymazal (2005) were also proved of similar BOD removal (76-83% and 85%).

Through this study, the greywater of residential area at Sindh Agriculture University, Tandojam, Sindh, Pakistan was treated by introducing constructed wetland system using three local aquatic plants. Based on DRI limits for irrigation, all the samples treated by all three plant species were fit with regard to TDS (450-2000 mg L^{-1}) being major part of TS and soluble P (<6.0 mg L^{-1}) with majority of the samples having pH in normal range of 6-9. The NO_3-N was the major form of N in greywater falling under slight to moderate category (5.0-30 mg L^{-1}) using all three plant species. Considering BOD, *Phragmites karka* was the only plant species, which brought the BOD values below the DRI limits of 80 mg L^{-1}. This species had maximum recycling potential for BOD and pH. The greywater quality after its treatment is recommended for use on crops initially at pot-house level. Future studies can be based on flow rates below and above 90 L day^{-1} in addition to multiple reed-bed system to improve the treatment efficiency with regard to majority of parameters. We also suggest the use of non-saline reed-bed mixture to have real picture with regard to salt content.

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