Greywater characteristics and loadings – treatment to promote reuse

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Abstract

Greywater is the wastewater produced in bathtubs, hand basins, kitchen sinks, dishwashers and laundry. Separation of greywater and blackwater and on site greywater treatment in order to promote its reuse for toilet flushing and/or garden irrigation is an interesting option especially in water deficient areas. The aim of this study was to characterize the different greywater sources in Greek households and to evaluate the performance of several simple physicochemical treatment systems consisting of sedimentation, coagulation, sand filtration and granular activated carbon filtration. Based on the results average daily greywater production was equal to 98 L per person per day and accounts for more than 70 % of the total household wastewater production (135 L per person per day). Among the different sources, laundry and kitchen sink are the main contributors to the total greywater load of organic carbon, suspended solids and surfactants, whereas dishwasher is the main source of phosphorus. Depending on sources, greywater accounts for as low as 20% of the total organic carbon wastewater load (in the case of light greywater sources), to as high as 75% of the total organic carbon load (in the case of the heavy greywater sources). On the other hand, the nutrients load of greywater is limited. The application of a physical treatment system consisting of sedimentation, sand filtration, GAC filtration and disinfection can provide for a final effluent with satisfactory characteristics for onsite reuse, while to provide for toilet flushing coagulation is also required ahead of sand filtration.

Keywords

Greywater characterization; greywater treatment; reuse; sand filtration; GAC filter

1. INTRODUCTION

Household wastewater consists of greywater and blackwater. Greywater is the wastewater produced in bathtubs, showers, hand basins, kitchen sinks, dishwashers and laundry machines and blackwater is the wastewater which comes from toilets (Eriksson et al., 2002), although wastewater originated from kitchen sinks is very often regarded as blackwater. Several studies have shown that greywater accounts for around 70% of the total household wastewater production, while at the same time it concentrates a rather limited portion of the total pollutional load of wastewater (Li et al., 2009; Donner et al., 2010; Antonopoulou et al., 2013). It has also been demonstrated that the quality characteristics of the several greywater fractions vary significantly depending on residents' habits (Palmquist and Hanaeus 2005; Eriksson et al., 2009; Hernandez Leal et al., 2007). Separation of greywater from blackwater and on site greywater treatment for toilet flushing and/or garden irrigation is an interesting option especially in areas facing water shortage problems. To apply such a reuse option greywater needs to be treated. Several greywater treatment systems have been tested in a high number of studies including physical, chemical and biological systems (Pidou et al., 2008). Based on their results it is anticipated that besides their satisfactory performance, biological greywater treatment systems are in some cases exhibiting several operating deficiencies on a household level due to i) nutrients deficiency of greywater, ii) the periodic greywater- wastewater production in residencies of temporary use and iii) the need for sewage sludge handling.

In view of the above the objectives of this study was to provide data regarding the quantity and quality of greywater and to evaluate the effectiveness of a rather simple physicochemical treatment system to treat greywater originating from different sources.

2. MATERIALS AND METHODS

2.1. Greywater quantity

In order to estimate the amount of greywater produced in Greek households, the average daily water consumption in three residences (H1, H2 and H3) with different characteristics (number and age of inhabitants, area) was recorded as the sum of wastewater produced in bathtubs, showers, hand basins, kitchen sinks, dishwashers laundry machine and toilets. All residencies located in the city of Athens, Greece. The estimation of the amount of greywater produced in bathtub/shower, hand basin and kitchen sink was achieved through the recording of the duration of the use the corresponding tap by each resident and for each activity on a daily basis (e.g. cooking activities, hand cleaning, dish and glass washing, fruit and vegetables washing in the kitchen). As a result the amount of greywater produced from each resident and for each activity was calculated as the product of the duration of the use of each source tap and its flowrate which was measured at each source in each residence at least three times. In the case of the laundry, dishwasher and toilet, calculation of the amount of wastewater was based on the recording of the number of their uses per day and the amount of water consumption per use (based on measurements in the case of laundry and dishwasher and technical characteristics of the toilet flush). The aforementioned measurements were taking place for a week in all residences in order to collect information of the average weekly habits of the residents.

2.2. Greywater characterization

Based on the relative contribution of each activity and each resident to the production of each greywater source (e.g. hand cleaning, teeth cleaning, shaving) a sampling protocol was implemented to produce composite samples from the three residences. According to the sampling protocol a total number of 60 samples were collected (3 residencies, 5 samples for each residence, 4 sampling campaigns). Samples were analyzed for conductivity, total solids (TS), total and volatile suspended solids (TSS, VSS), total and soluble COD, BOD_5, linear alkylbenzene sulfonates (LAS), ammoniacal nitrogen (NH_4-N), oxidized nitrogen (NO_x-N), total kjeldahl nitrogen (TKN), total nitrogen (TN), phosphates (PO_4-P), phosphorus, heavy metals and emerging contaminants.

2.3. Greywater treatment experiments

Greywater samples from the bathtub, the handbasin, the laundry and the kitchen were collected every two days and being processed in the experimental units. Systems 1-2 consisted of a 10 L sedimentation tank, followed by a sand filter and a GAC filter. Systems 3-5 were a modification of Systems 1-2 with the incorporation of a coagulation unit ahead of the sedimentation tank and the two filtering units (sand filter and GAC filter). System 6 consisted of a coagulation unit, the sand filter and the GAC filter. The contribution of each greywater fraction to the total untreated greywater being processed to each experimental system is presented in Table 1. Greywater retention time in sedimentation tank of all experimental systems was equal to 20 h. The supernatant of sedimentation tank was fed initially to sand filter (5 cm plexiglass column) and eventually passed through the GAC filter at a flowrate of 2.8 L/h and a filtering velocity of 1.4 m/h. For the evaluation of the optimum coagulant dose ($AL_2(SO_4)_3$ x$14H_2O$) a series of jar tests were performed. Samples from the untreated greywater, the supernatant of the sedimentation tank and the effluent of the sand filter and the GAC unit were collected twice a week and subsequently being analyzed for turbidity, TSS, VSS, CODt, CODs, LAS an emerging contaminants.

2.4. Analytical methods

Greywater samples were analyzed for pH, conductivity, TS, TSS, VSS, total and soluble COD and LAS. All analyses were performed according to Standard Methods (APHA, 2005). The determination of emerging contaminants was achieved using a chromatographic method developed by Samaras et al. (2011).

Table 1: Set up of the several experimental treatment systems and the contribution of each treatment source to the total untreated greywater used in the experiments

Treatment System	Greywater source				Treatment stages			
	Kitchen	Laundry	Bath/shower	Handbasin	Coagulation	Sedimentation	Sand filter	GAC filter
System 1			77%	23%		×	×	×
System 2		29%	55%	16%		×	×	×
System 3		29%	55%	16%	×	×	×	×
System 4	13%	48%	25%	14%	×	×	×	×
System 5	31%	38%	20%	11%	×	×	×	×
System 6	13%	48%	25%	14%	×		×	×

3. RESULTS AND DISCUSSION

3.1 Quantitative greywater characterization

The results of the quantitative analysis of different greywater sources and toilet flushing are presented in Table 1 (in terms of average values and standard deviation), along with the results of other studies which have been performed to other European countries. Furthermore the contribution of several greywater sources to the total greywater production for households H1, H2 and H3 and the daily evolution of the different sources of greywater and blackwater are illustrated at Figure 1. According to the results average greywater production was estimated to be 98.4±11 L per person per day, whereas the total household wastewater production was equal to 135.6±11 L per person per day. These values are very similar to the ones reported in several studies performed in either European countries (Antonopoulou et al., 2013; Penn et al., 2012; Krozer et al 2010; Revitt et al., 2011). Figure 1a presents the contribution of each source to the total greywater production for the three households. Based on the results it is anticipated that major sources of wastewater are toilet flushing, bathtub and kitchen sink. The major portion of greywater (to the order of 60%) is produced in bathrooms (bath tub and hand basin). Furthermore wastewater production presents a great variability throughout a week (Figure 1b). Beyond this variability, the ratio of greywater to the total wastewater showed little variation throughout the week (68-77%). On average, greywater accounts for 72.5% of the total wastewater produced, a value which is very similar to the respective ones reported for Israel (Penn et al., 2012), Sweeden (Palmquist and Hanaeus 2005) and China (Zhang et al., 2009).

Table 1: Quantitative characteristics of several sources of household wastewater (all values in L/pe/d)

Sources	**Greece** (present study)	**Greece** Antonopoulou et al., 2013)	**Israel** (Penn et al., 2012)	**Holland** (Krozer et al., 2010)	**Denmark** (Revitt et al., 2011)
Hand basin	11.3±1.1	8.6	18	4	-
Bath/shower	37.5±4.3	33.9	39.2	47	43
Kitchen	29.7±5.0	12.2	26.6	7	25
Laundry	19.2±5.0	21.3	16.6	27	17
Dish washer	0.6±0.4	6.6	-	1	-
Total greywater	98.4±11	82.6	100.4	86	85
Toilet flushing	37.2±2.5	59.4	37.7	39	27
Total wastewater	135.6±11.5	142	138.1	134	119

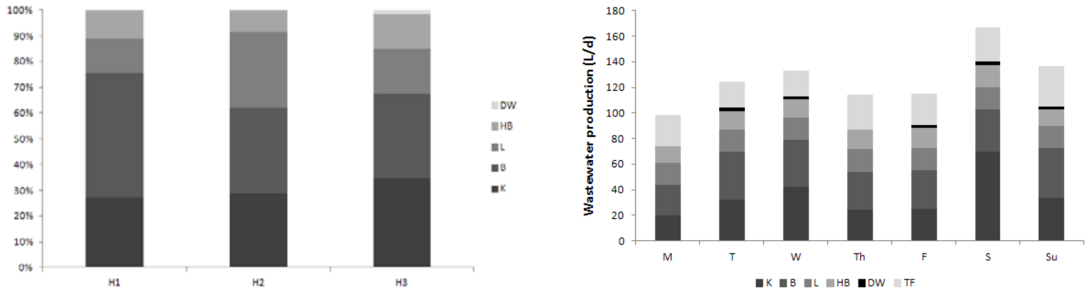

Figure 1: (a) Contribution of several sources to the total greywater production for households H1, H2 and H3, (b) Daily evolution of wastewater production of several sources

3.2 Qualitative greywater characterization

Based on the sampling protocol 60 greywater samples were collected and subsequently being analyzed. The main quality characteristics for the several greywater sources are presented in Table 2 (in terms of average values and standard deviation).

According to the results average pH in kitchen greywater is rather neutral (6.90), whereas laundry and dishwasher greywater is alkaline with an average pH value of 8.2 and 10 respectively. These values are very close to the ones reported by other researchers (Antonopoulou et al. 2013; Eriksson et al., 2002). The high pH values recorded in dish washer samples are correlated to the high values of conductivity of the same samples. More specifically average conductivity of dish washer samples was more than 7 times greater than those of shower and hand basin samples, 5 times greater than kitchen samples and more than 3 times greater that laundry samples.

Concentration of organic carbon exhibit a high variability among different sources of greywater. More specifically total COD average concentrations varied between 390 – 2072 mg/L whereas BOD_5 concentrations varied between 185-1363 mg/L (Table 2). Laundry greywater exhibits the higher COD concentration with values equal to 2072±1401 which are almost two times greater than the respective ones from shower, handbasin and dish washer greywater samples and almost doubled of these of kitchen samples. Soluble COD of laundry samples account for 56% of the total COD and the average COD/BOD_5 ratio is equal to 1.5; an indication of increased biodegradability of laundry greywater (Table 2). Kitchen greywater presents also high organic carbon concentrations (mainly due to the presence of drink and food residuals and dirt from vegetables) with values of 1119±476 mg/L and 831±358 mg/L for COD and BOD_5 respectively, presenting the lower soluble COD fraction and the greater biodegradability among other greywater fractions (COD/BOD_5 ratio equal to 1.3). On the other hand, dish washer samples present the higher soluble COD fraction (74%) and the lower biodegradability (COD/BOD_5 ratio equal to 2.2). The lower organic carbon concentrations were recorded in bathroom samples (shower and handbasin) which present an average COD/BOD_5 ratio of 1.4.

Based on mass fractions, it is concluded that kitchen sink and laundry are the two more significant contributors of organic carbon (Figure 2). On the other hand, greywater produced in bathrooms (handbasins and bathtubs/showers) seems to be lighter with respect to its suspended solids, organic matter and nutrients loads.

The total nitrogen and phosphorus load of all greywater sources is rather minimal when compared to that of mixed household wastewater. The only significant greywater source of phosphorus is the dishwasher due to the use of high phosphorus detergents – soaps (Figure 2). More than 60% of the total greywater surfactants load expressed as LAS is originated from laundry greywater, whereas kitchen sink is an appreciable contributor to the total surfactant load of greywater (Figure 2).

Table 2: Qualitative characteristics of several greywater sources (all values in mg/L except pH and conductivity)

Greywater source/type	pH	Conductivity (μS/cm)	TS (mg/L)	COD_t (mg/L)	COD_s (mg/L)	BOD_5 (mg/L)	LAS (mg/L)	TN (mg/L)	TP (mg/L)
Bath/shower	7,5±0,1	318±29,9	325±55,3	390±125	193±113	263±83,9	78±34	2,7±2,2	0,10±0,14
Hand basin	7,6±0,2	318±26,8	373±96,0	427±192	272±203	305±129	42±26	2,5±1,9	1,3±2,0
Kitchen	6,9±0,4	449±341	883±426	1119±476	518±225	831±358	87±76	6,5±5,0	2,7±3,1
Laundry	8,3±0,8	653±423	1085±608	2072±1401	1165±920	1363±950	436±288	6,2±5,3	1,2±0,81
Dish washer	10±0,2	2199±752,6	2535±1053,4	411±59	307±2,9	184,6±24,8	7±5,6	<0,5	187,1±51,4

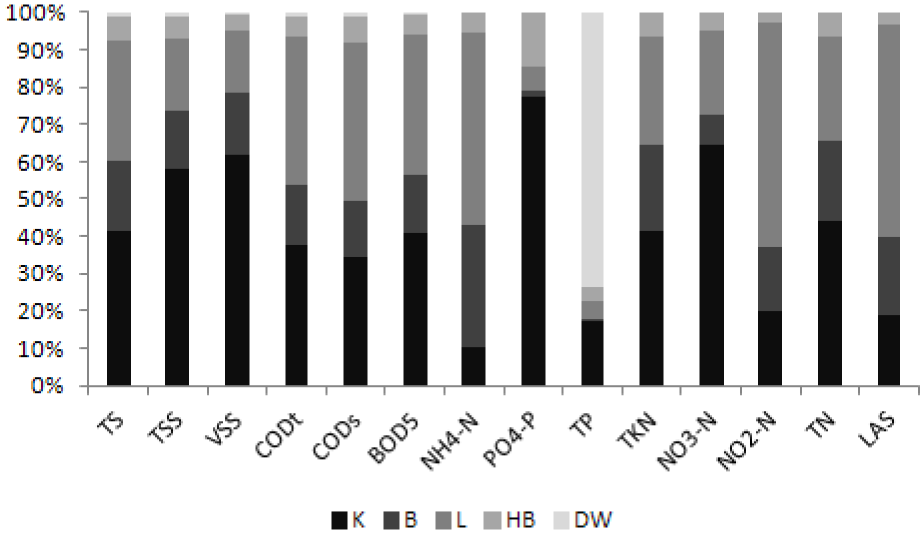

Figure 2. Contribution of several sources to the total greywater load (K: kitchen sink, B: bathroom, L: laundry, HB: handbasin, DW: dishwasher)

3.3 Greywater treatment experiments

Figure 3 illustrates effluent turbidity and TSS concentrations for the six experimental systems, while Figure 4(a)-4(d) presents the contribution of each treatment stage on the removal of TSS, CODt, CODs and LAS. Based on the results turbidity decreased significantly throughout all the experimental systems from values around 52-115 NTU (depending on the type of the untreated greywater used) to values between 0.6-11 mg/L (depending on the experimental system employed). Similarly total COD concentrations decreased from 350-670 mg/L to 8-34 mg/L and LAS decreased form values around 40-82 mg/L to values lower than 1 mg/L.

The contribution of the three treatment units to the total pollutants' removal was dependent to the type of system. For example in the case of systems without coagulation (Systems 1-2) the role of sand filter on the removal of TSS, total and soluble COD and surfactants was rather limited and activated carbon filtration was the primary removal mechanism for almost all pollutants.

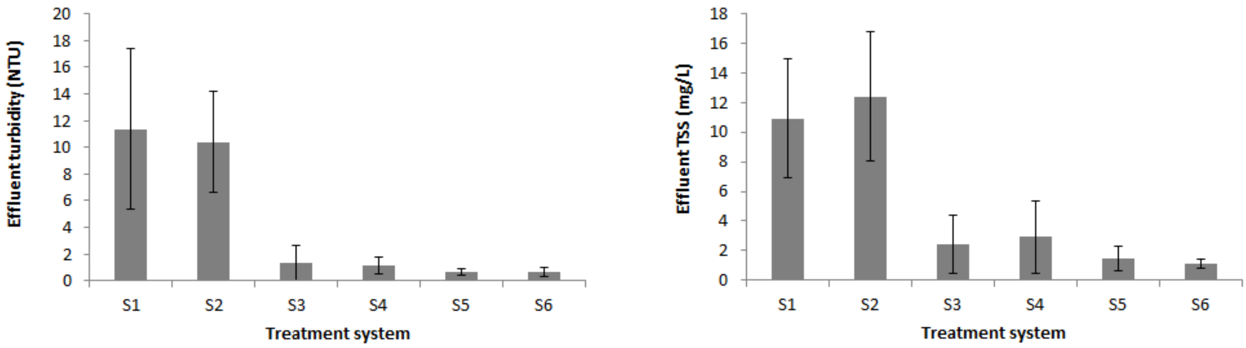

Figure 3. Effluent turbidity and TSS concentration for the six experimental systems

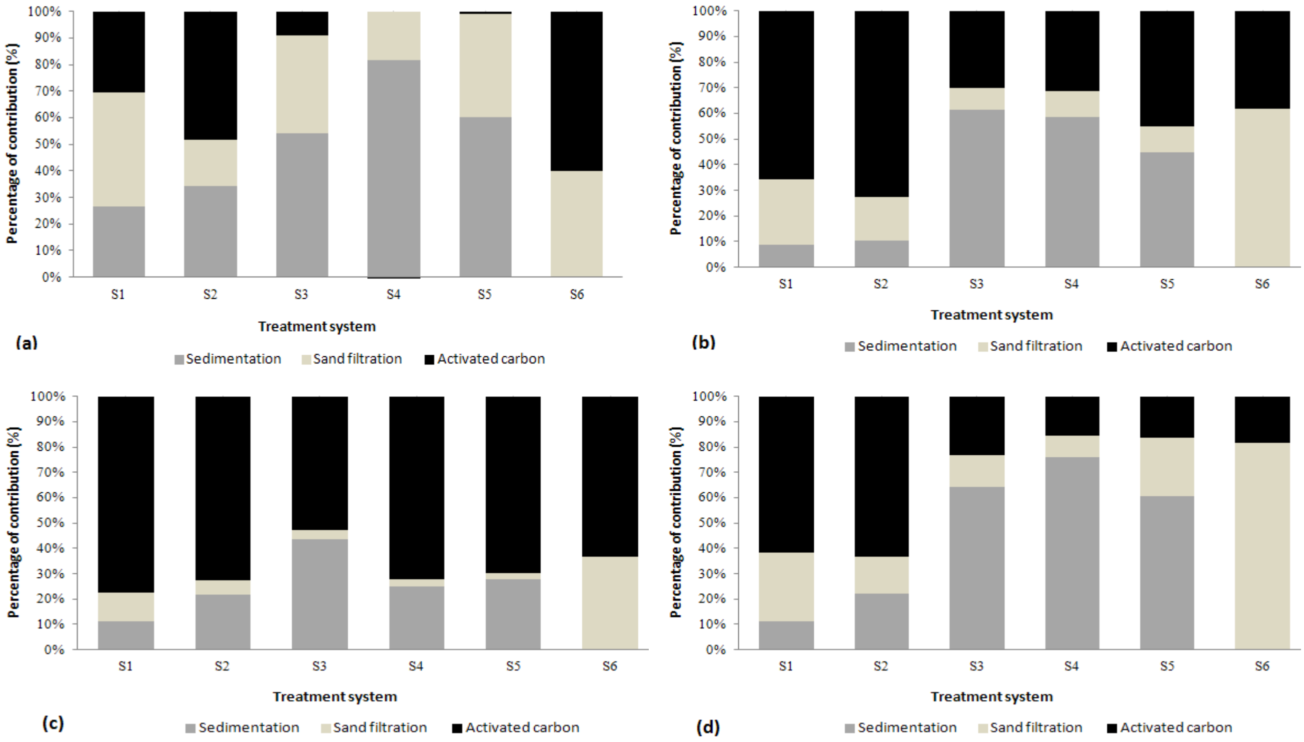

Figure 4. Contribution of each treatment unit to the removal of (a) TSS, (b) CODt, (c) CODs and (d) LAS from greywater

On the other hand, following addition of the coagulation step, the effluent quality was significantly improved (Figure 3). More specifically effluent turbidity was as low as 1 NTU whereas average TSS, total COD and LAS concentrations in the effluent ranged between 1-3 mg/L, 13-34 mg/L and 1 mg/L respectively. As illustrated in Figure 4, due to coagulation, the contribution of sedimentation to the total turbidity, TSS, total COD and LAS removal increased significantly, whereas activated carbon adsorption was the dominant mechanism for the removal of soluble COD. As a result the cleaning frequency of the sand filter was reduced from 9-10 d for the case of Systems 1-2 to 2-6 d for Systems 3-5 and almost 1.5 d for the case of direct filtration (System 6).

In view of the above, and by taking into account the national limit values for wastewater reuse (Joint Ministerial Degree 145116/8-3-2011) (turbidity < 2 NTU and TSS < 2 mg/L for 80% of the samples), it is anticipated that a system consisting of coagulation, sedimentation, sand and activated carbon filtration supplemented by a disinfection unit can provide for greywater reuse for both unrestricted irrigation and toilet flushing.

4. CONCLUSIONS

The average daily wastewater production in the surveyed households was equal to 135 L per inhabitant, while greywater was equal to 98 L per inhabitant. The major sources of greywater are bathtub and kitchen sink. Greywater characteristics are highly variable as they depend on the living standards, the activities, the income and the habits of the residents. Among the different sources, laundry and kitchen sink are the main contributors to the total greywater load of organic carbon and suspended solids, whereas bathtub and hand basins are the less polluted sources of greywater.

Depending on the sources, greywater accounts for as low as 20% of the total organic carbon wastewater load (in the case of light greywater sources), to as high as 75% of the total organic carbon load (in the case of the heavy greywater sources). On the other hand, the nutrients load of greywater is rather limited. The application of a physical treatment system consisting of coagulation, sedimentation (mainly for equalization purposes), sand filtration, GAC filtration and disinfection can provide for the production of a high quality effluent for onsite reuse purposes.

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