Characterization of greywater by appliance- Pattern of discharge along the day

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Abstract

To improve water resources sustainability it is imperative to consider different approaches of water management, such as water reuse strategies.

Greywater decentralised reuse seems to be more advantageous than total wastewater reuse, since it is less polluted and so, it is easier and cheaper to treat. To guarantee the success of a greywater reuse strategy it is necessary to know in detail the available flow by appliance and its variation along the day, as well as its quality.

The diurnal variation of activity for each major appliance is studied in this paper, as well as, the typical medium volume associated to each discharge, in order to derive Volume distribution graphs per domestic device. Additionally, a range of quality parameters were determined in order to reach pollutographs per appliance. This will give important information to the greywater reuse management.

Keywords: Greywater, reuse, pattern of discharge.

INTRODUCTION

Water is undoubtly an unquestionable natural resource which needs to be preserved, the main activities that depend on it are also the ones that contribute mostly to its degradation.

Water resources are being, over decades, intensively over explored and polluted, and it is estimated that in a few years, it is reached highly values of water stress in Europe. Portugal is already in the ranking of countries with medium water stress (10-20%) (Melo-Baptista, J. 2002). To avoid the deterioration of this situation it is imperative to consider different approaches of water management, such as water reuse strategies.

Greywater decentralised reuse seems to be more advantageous than total wastewater reuse, since it is less polluted and so, it is easier and cheaper to treat. To guarantee the success of a greywater reuse strategy it is necessary to know in detail the available flow by appliance and its variation along the day, as well as its quality. There are some investigation carried out on this subject, that has shown how usage varies significantly along the day and between domestic devices (Butler, D., 1991; Butler D. et al, 1995). In fact the quantity of wastewater generated inside a dwelling depends on several factors and it has highly variation patterns. In some European capitals the wastewater flow generated per day in a dwelling may reach 586 L. According with NSW, (2006) greywater represents 68% of the total wastewater generated in a house and 49% of this comes from baths, 34% from laundry, 10% from the kitchen and 7% from the washing basin. Friedler et al., (2005) refers a capitation of 100-150 L/person.day and in Portugal, it is estimated a range of 100-180 L/person.day (PNUEA, 2001). The same study refers that baths are responsible for 66% of the total water consumed. Depending on the type of reuse that is considered, all the studies agree on the fact that greywater generated in a house is enough to supply a reuse strategy inside the same. Friedler, (2004) refers that a greywater reuse scheme would consume only 50-65% of the total greywater produced.

Despite this research, the pattern and daily total production of wastewater from domestic sanitary appliances is a subject area in which a small amount of research has been carried out. The accurate measurement of flow for single domestic appliance is difficult due to the intermittent nature of the flows from these sources. There is some research that determined the frequency and duration of usage of each domestic device and the typical volume and flow rate per appliance and per usage (Butler & Gatt, 1995). Although conceived to be clean greywater is polluted and contaminated, and has a great variability. There is some research on the quality of greywater and its variation by source and inside the same source, for instance literature reports important differences for washing machines between the effluents of different cycles and the same can be expected from dishwashers (Eriksson et al, 2002; Christova-Boal et al, 1996; Friedler, 2004, Surendan & Wheatley, 1998; Rose et al, 1991; Burrows et al, 1991; Shin et al, 1998; Nolde, 1999). Almeida et al, (1999) calculated at-source pollutographs using survey data of domestic appliance usage together with measured flows and quantities of pollutants per use.

The diurnal variation of activity for each major appliance is studied in this paper, as well as, the typical medium volume associated to each discharge, in order to derive graphs with the volume distribution along the day, per domestic device. Additionally, a range of quality parameters were determined in order to reach pollutographs per appliance. This will give important information to the greywater reuse management.

AREA DESCRIPTION

The study was undertaken in Vila Real, a city from the northeast of Portugal, which has a population of 50 000 spanning 377,08 km^2. The 14 dwellings affected to this research were unfamiliar, varying in the number of inhabitants from 1 to 5 per house, with different life styles, in order to get a representative sample of the population area.

METHODOLOGY

Medium pattern of discharge along the day per appliance

To comply the proposed goals, and thereby to proceed to greywater quantity characterization by domestic device and its distribution along the day, a questionnaire was distributed for 11 different dwellings. Volunteers were given a set of diary sheets and asked to record each time a particular appliance was used and waste flow generated, during a complete week. The appliances monitored were the washbasin, the bathtub, the washing machine, the kitchen sink, the dishwasher and the toilet flush.

From this data it was possible to calculate an average number of discharges and their standard deviation, per hour per appliance and simultaneously know the total number of discharges per domestic device.

Volume per discharge per appliance

At the same time, in another 3 dwellings, data was collected in order to know how much volume was discharged in each appliance per usage. In this part of the survey each inhabitant registered the volume before and after each usage, always taking very careful to measure only one use, each time and so there were not simultaneous uses, during the research period.

The sample consisted in 563 records of volume discharged in each usage, 259 records of washbasin, 84 records of baths, 87 records in the kitchen sink, 103 records of toilet flush, 14 records of the wash machine and 16 records of the dishwasher. After the sampling, it was calculated the medium value of volume discharged per usage and the standard deviation using Excel.

Volume distribution along the day per domestic device

With the data collected from the previously described methods it was possible to prepare charts that translate the pattern of daily discharges per appliance, and so to know in detail the frequency and distribution of usage of each particularly domestic device over a day. Moreover it is possible to know the relative contribution of each domestic device to the total volume discharged, over a day.

Pollutographs

Greywater quality per domestic device. In order to determine greywater quality per domestic device, independent samples were taken from eight distinct houses collected and treated at the same day. The houses were unifamiliar, varying in the number of inhabitants from 2 to 6 per house. Greywater was separated by its origin and were collected water samples in both rooms that generated effluents: kitchen and bathroom. In each room, waters were collected concerning its origin: (i) in kitchen we took samples in sink, dishwasher and washing machine, and (ii) in the bathroom samples were taken in wash basin, bath and bidet. This last appliance is widespread in Mediterranean Region.

In each sample the following physic-chemical parameters were analyzed: pH, electric conductivity, TDS, temperature and COD. All of them, except COD, were analyzed with sensors. In respect to microbiological parameters it was determined the total and fecal coliform content in the laboratory.

Derivation of pollutographs. The patterns of quality for individual appliances have been calculated from the volume graphs associated with an average of pollution concentration per device. From the volume graphs is taken the distribution of volume discharged along the day, per person, per appliance (L/person), knowing the medium concentration of each parameter per domestic device (mg/L, g/L or CFU/100ml) it is possible to know the quantity (mg, g or CFU) discharged along the day. Relatively to TDS the value used to design the pollutographs was the maximum value of all.

RESULTS

Medium pattern of discharge along the day per appliance

A relative standard pattern was obtained for the discharges per domestic device along the day (Figure1), distinguishing two separate groups with different peaks: the group of devices that belong to the W.C. and the group of devices that belong to the kitchen. The first group demonstrated a high morning peak and a lower evening one. The second one has the highest peak at dinner time and two lower peaks at breakfast and lunch. The washing machine does not reveal any obvious diurnal pattern. During night hours (01:00-06:00), the toilet flushing and the washing basin constitutes the domestic devices with the highest value of discharges.

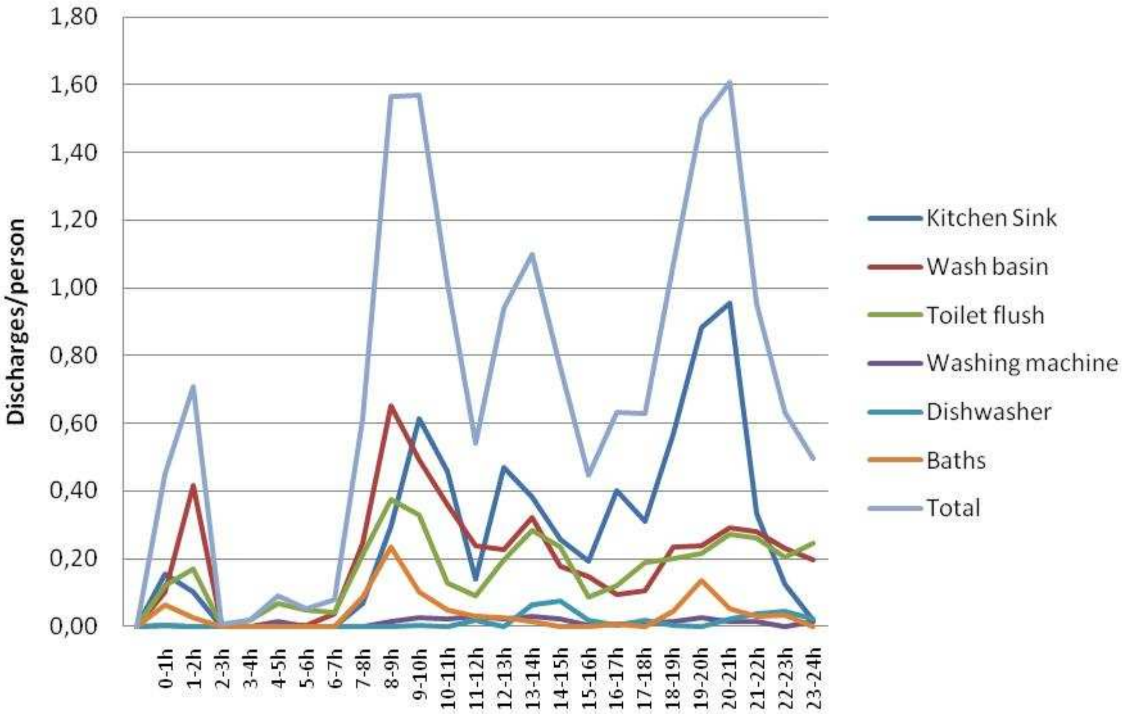

Figure 1. Pattern of discharges per inhabitant per domestic device along the day.

Figure 2 summarises the individual contribution of each appliance to the total number of discharges. The results clearly indicate the importance of the kitchen sink, since it represents the highest contribution to the stream, in terms of number of discharges. It is important to state that the value of standard deviation associated to this type of research is always very high, and so, these results have to be analysed with the proper reticence.

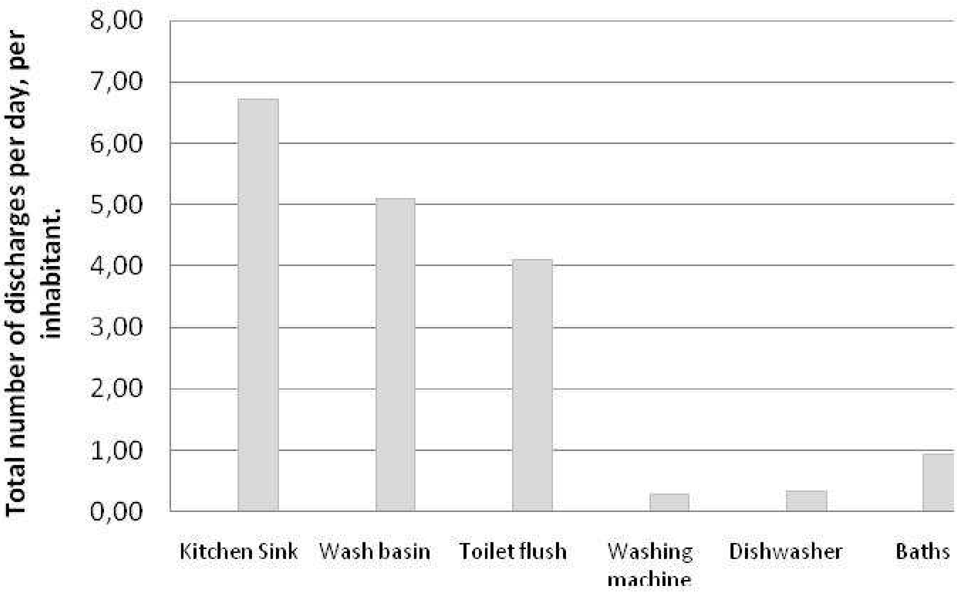

Figure 2. Individual contribution of each appliance to the total number of discharges.

Volume per discharge per appliance
Table 1 summaries the volume associated with each discharge and per inhabitant, to each domestic device, as well as, its standard deviation.

	Washbasin	Bathtub	Kitchen-Sink	Toilet-flush	Washing machine	Dishwasher
Mean	2,5	38,2	6,8	8,8	25,2	9,5
SD	1,1	10,2	17,8	4,1	11,9	1,4

Table 1. Volume used from each domestic device per discharge and per inhabitant.

The results underline the importance of bath in terms of volume discharged per usage, following the washing machine. Once more, it is important to highlight the standard deviation values, since the volume per discharge depends on several factors associated with the household activities such as time of usage. Given the significant variability in the characteristics associated with each usage, further determinations are advisable. Relatively to toilet flush, the volume released depends on the type of flush. The traditional one waste between 7 to 15 L per discharge and a dual discharge flush varies between 3 to 6 L, according to the PNUEA, (2001). The washing machine discharge depends on the model and on the program chosen.

Volume distribution along the day, per domestic device
Combining the results of the two previous parts it was possible to obtain the Volume distribution graphs per domestic device, as well as know the volume discharged per day per inhabitant and per appliance, reaching the total volume released per day, per inhabitant. Relatively standard pattern was obtained for the total volume released of at the household, with a high morning peak and a lower evening peak (Figure3). It is possible to notice the difference between the volumes per the several domestic devices. Bathtub represents the appliance with the major volume released reaching 9 L/person between 8 and 9 a.m. (Figure 3).

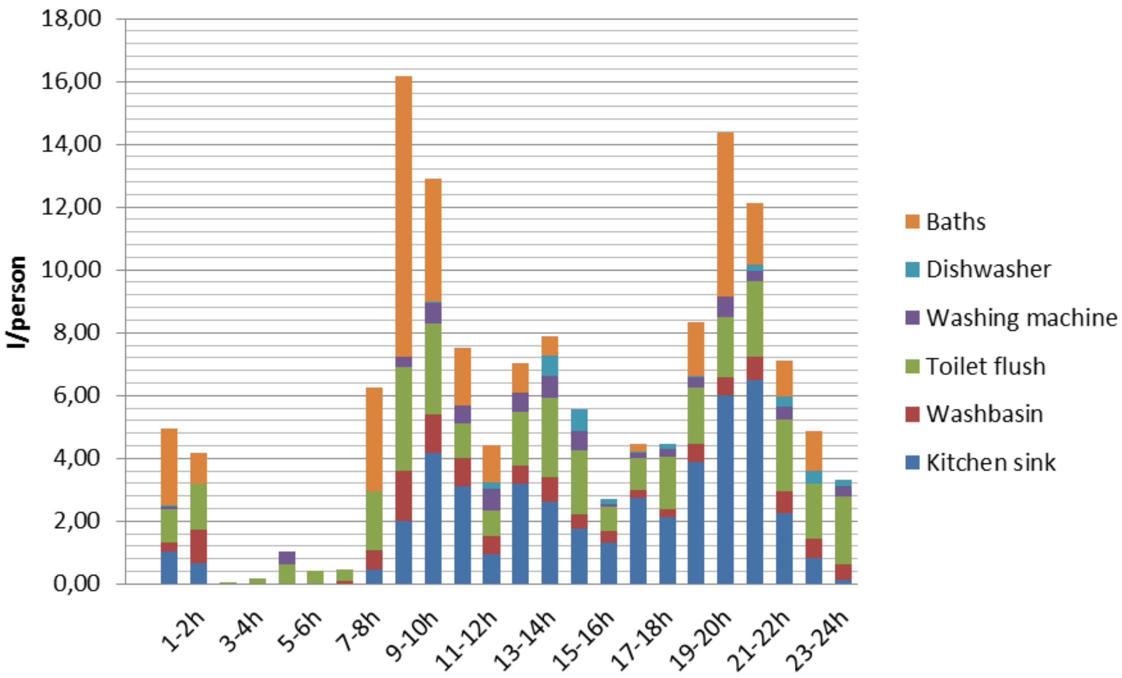

Figure 3. Distribution of the volume released along the day per domestic device.

Figure 4 shows the medium volume released per inhabitant, per day, per appliance. As it can be verified the major contribution to the total volume released per day match with kitchen sink, following toilet flushing and the bathtub.

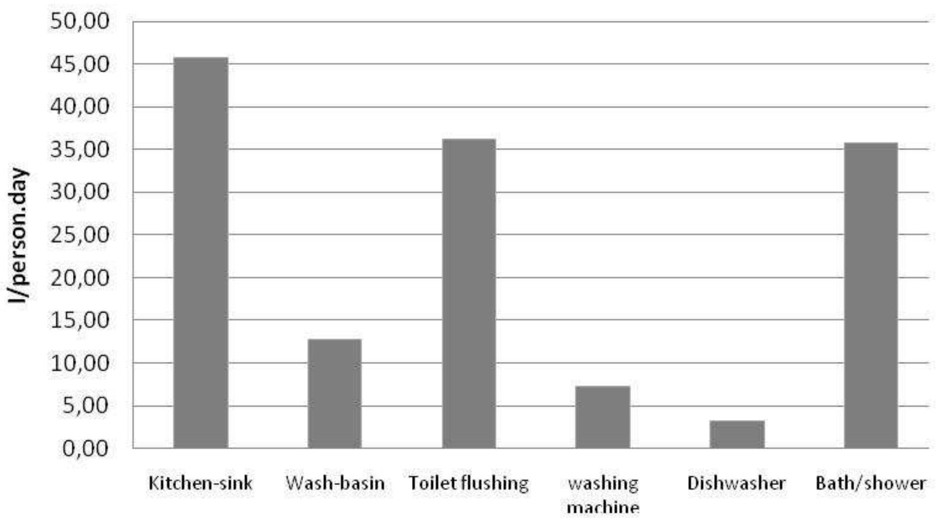

Figure 4. Volume released per inhabitant, per day, per appliance.

Comparison with literature values (Laak, 1974; Siegriest et al., 1976) show that the measurement results are of the same order of magnitude. Differences are due to the variability associated with habits, since it vary geographically and in time.

Derivation of pollutographs

As said before, samples from raw greywater were analysed for temperature, pH, conductivity, TDS and COD. In Table 2 there are presented the mean values of each parameter (n=8) by appliance, as well as its standard deviation.

Source	pH	COD	Condutivity	TDS
		(mg/l)	(µs/cm)	(mg/l)
Kitchen Sink	7,3±0,5	1781,5	150,1±105,8	96,1
Washing machine	10,1±0,3	821,1	3677,1±2826,4	2353,4
Dishwasher	8,5±1,7	1234,5	1560,8±833,8	998,9
Wash basin	7,1±0,5	196,8	100,9±21,1	64,6
Bidet	7,3±0,3	7,9	67,5±17,1	43,2
Bath/shower	6,7±1,1	540,2	94,6±42,3	60,6
Drinkable water	6,7±0,8	-	71,9±73,5	46,0

Table2. Pollutant concentration per domestic device.

To investigate the concentration of bacteria in raw greywater we enumerated total and faecal coliforms (Table3).

Source	Total Coliforms (CFU/100ml)		Fecal Coliforms (CFU/100ml)	
	Mean	SD	Mean	SD
Wash basin	$5,43x10^4$	$3,53x10^4$	$3,33x10^2$	$5,16x10^2$
Bidet	$1,73x10^5$	$6,05x10^4$	$2,17x10^2$	$3,87x10^2$
Bathtub	$2,22x10^5$	$1,10x10^5$	$4,45x10^4$	$6,04x10^4$
Kitchen sink	$6,74x10^6$	$3,31x10^5$	$7,00x10^3$	$8,85x10^3$
Washing Machine	$5,72x10^4$	$4,00x10^4$	ND	ND
Dishwasher	$2,82x10^6$	$2,62x10^5$	$1,50x10^5$	$1,67x10^5$

Table 3. Total and Faecal coliform concentration in each domestic device.

As said before, attaching different pollutant concentrations to each device permits the calculation of pollutographs. The use of overage values for volumes and concentrations associated with each device has been used and consider acceptable in a similar study carried out by Almeida et al, (1999). In fact, quality varies with several factors and it was already proved by Friedler & Butler, (1996).
It is advisable to discuss the results considering the partial contribution of volumes and concentrations to the total amount of pollutants. Indeed, there are some cases that the total quantity is mainly due to volume and in contrast, in other cases the total quantity is mainly due to pollution concentration (Table 4).

Source	%Volume discharged	COD	TDS	Total coliform	Fecal coliform
	(%/day.person)	(%)	(%)	(%)	(%)
Bath/shower	34,0	**11,8**	2,0	2,0	22,0
Wash-basin	12,0	**4,3**	2,0	1,0	0,2
Kitchen sink	44,0	**38,9**	2,0	68,0	3,5
Dishwasher	3,0	**27,0**	28,0	28,0	74,3
Washing Machine	7,0	**18,0**	66,0	1,0	0,0

Table 4. Relative contributions (%) in terms of volume and concentration of pollutants/contaminants of different sources.

As expected, the peaks of mass are coincident with the volume peaks. COD quantity is considerably high, reaching more than 11 g per person in kitchen sink between 21 and 22 O'clock. This value is due to two reasons: kitchen sink is the device that produces almost 44% of the volume and at the same time it is the appliance that contributes with the higher concentration in COD (39%). Due mainly to the volume discharged, bathtub presents a major mass of COD, reaching more than 5 g per person between 8 and 9 O'clock. Dishwasher presents a maximum value of 1 g per person of COD following the washing machine with 370 mg per person and finally the wash basin with 320 mg of COD per person. Despite its low contribution to COD amount, the washing machine and the dishwasher presented higher concentrations than bathtub (Figure5).

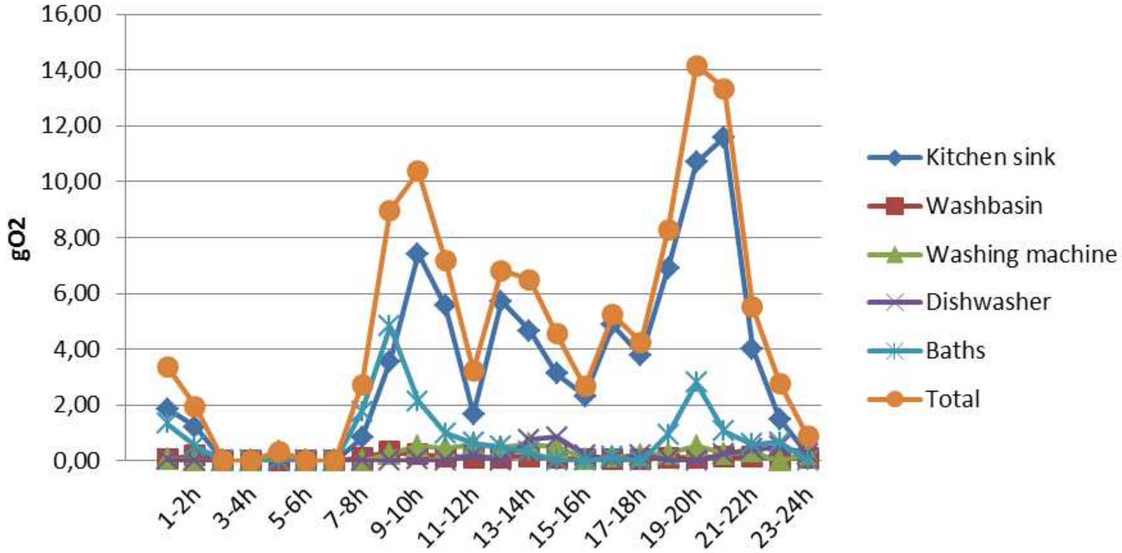

Figure 5. Quantity of COD (g) per person, per domestic device along the day.

The washing machine presents the higher values in terms of TDS discharged, reaching the 1,5 g per person. In this case the quantity presented is mainly due to the pollution concentration. Actually the washing machine presents the higher value for the concentration in TDS and despite the little volume discharged, it constitutes the domestic device that most contributes to TDS mass (Figure 6).

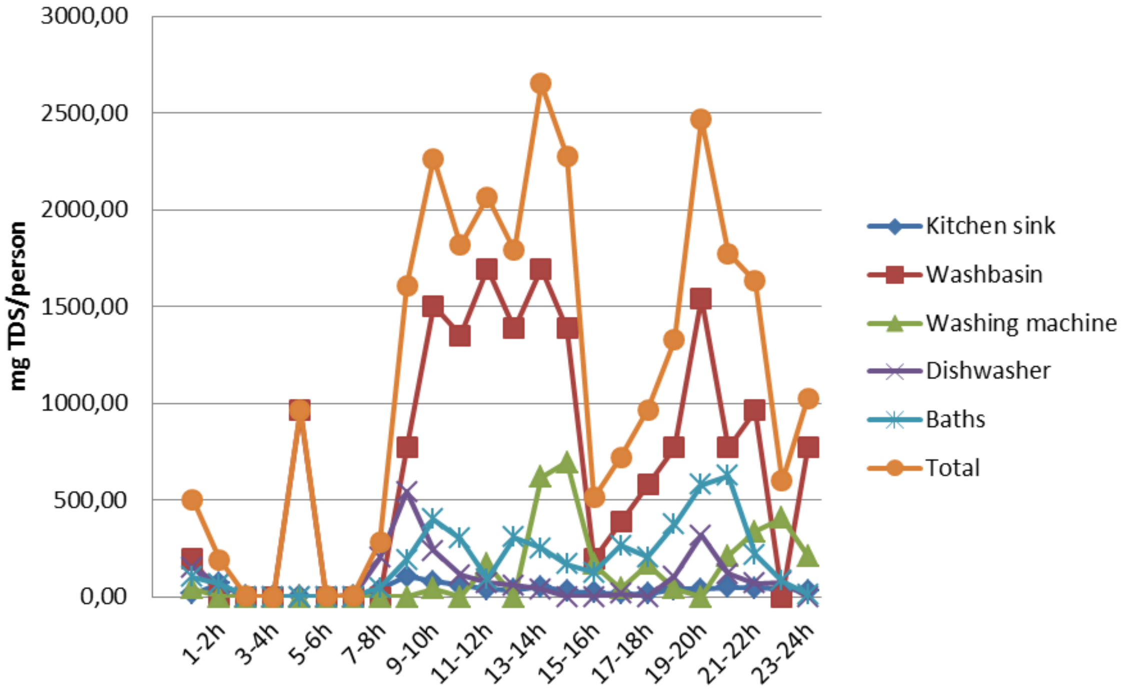

Figure 6. Quantity of TDS (g) per person, per domestic device along the day.

Regarding to microbiological contamination, namely to total coliform (TC) amount, kitchen sink is the domestic device with the major contribution followed by the bathtub and the dishwasher. Bathtub contribution in terms of TC is largely due to the volume discharged, unlike the dishwasher that presents a high value of TC concentration. Actually, although the higher volume discharged in the bathtub, in some periods, the contribution of these two appliances is similar (Figure 7).

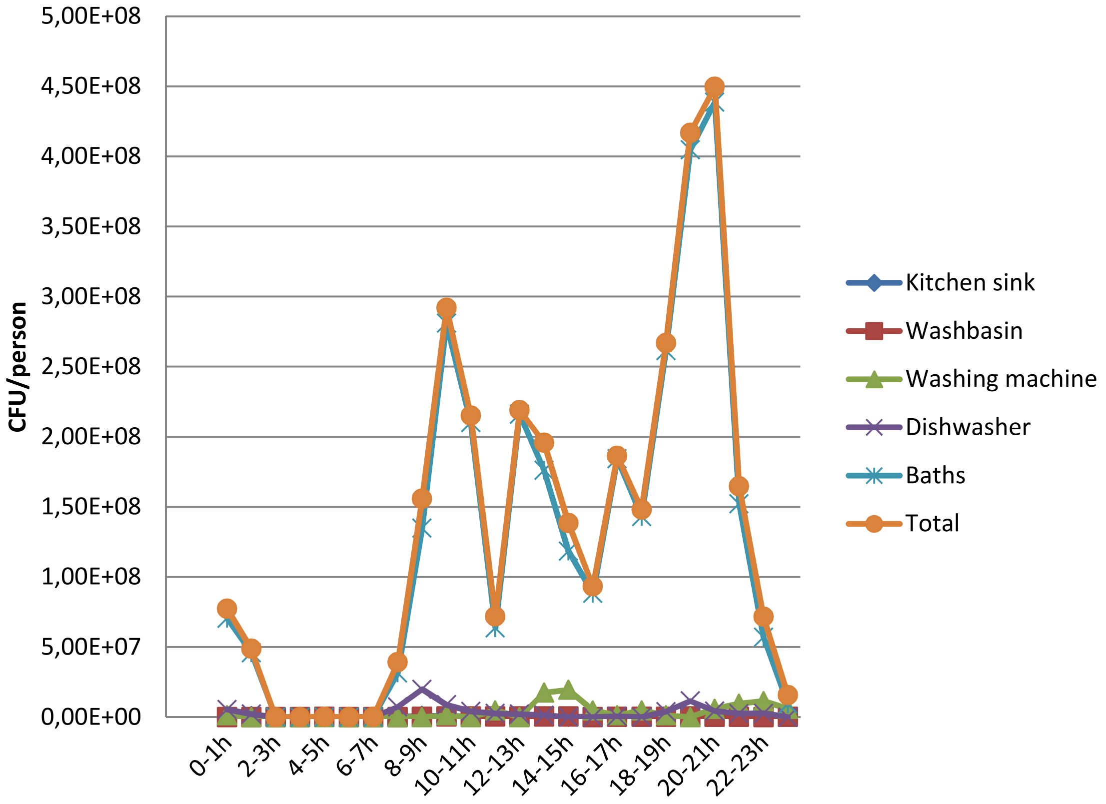

Figure 7. Total coliform CFU per person, per domestic device along the day.

Finally, regarding to faecal coliform (FC) amount, bathtub is the device that provides the higher contribution and the washing machine presents no FC (Figure 8).

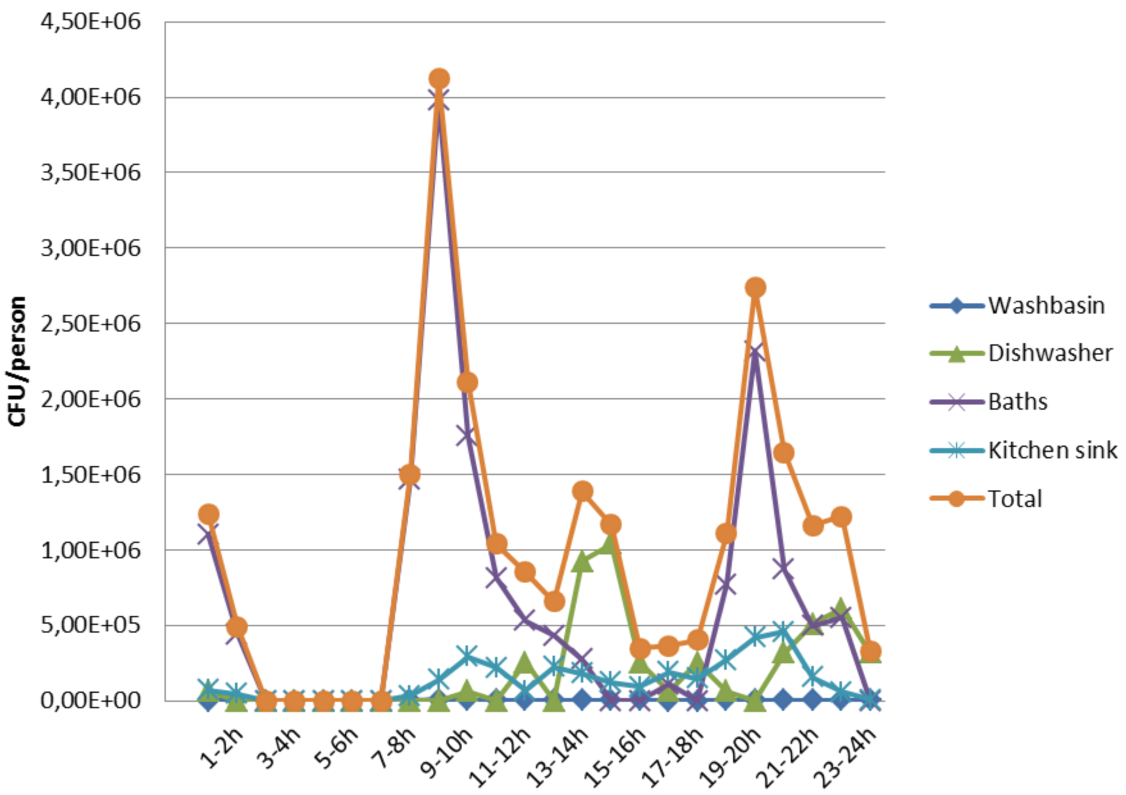

Figure 8. Faecal coliform CFU per person, per domestic device along the day.

CONCLUSION

In this paper is presented a method for estimating individual household volume distribution graphs and pollutographs, based on household appliance use. Volume distribution graphs are derived from data on appliance usage frequency and volume of use and on quantity per usage. Within the domestic appliances, the kitchen sink, the dishwasher and the washing machine were found to be the appliances that most contribute towards greywater pollution. Bathtub gives an important contribution for the faecal coliform contamination.

The proposed approach can be used to derive dry weather flow inputs to water quality. It also provides a mean to assess the impact of changes in household water consumption.

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