A comparative study of greywater from domestic and public buildings

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ABSTRACT

Greywater (GW) can be an important resource for urban water consumption, replacing potable water for purposes that do not require drinking water quality. If applied on a large scale, this practice will reduce the potable water demand and the wastewater produced in urban areas, minimizing the negative impacts and costs of water extraction and wastewater treatment. A correct characterization of GW is important to assess its potential for a direct reuse or, if not possible, to make a correct definition of a feasible and cost-effective treatment system. This article aims to contribute to the characterization of GW produced in washbasins and showers in domestic and public buildings. A compilation of several works on GW collection and sampling produced by the authors is presented. Samples were taken from GW produced in showers and washbasins in households, changing rooms and in a restaurant. Results are compared with values presented in similar studies and compared with standards and guidelines published in different countries.

Key words | greywater, sustainability, water reuse

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INTRODUCTION

Greywater (GW) is defined as wastewater from showers, baths, hand basins, laundry, washing machines and kitchen sinks. Many authors and guidelines around the world consider GW as wastewater only from showers, baths and hand basins, excluding the more contaminated water from washing machines and kitchen sinks. Compared to domestic wastewater, GW generally contains lower concentrations of organic pollutants and nutrients but a higher amount of surfactants (Paris & Schlapp 2010). GW has the potential to be an important resource for urban water consumption since it can replace potable water in uses that do not require drinking water quality (such as irrigation and toilet flushing), reducing the demand on potable water supply. However, as Mandal *et al.* (2011) point out, this is not the only benefit of this practice. GW reuse also conserves water resources for potable uses and decreases the amount of wastewater sent to the downstream wastewater infrastructure (including collection, treatment and disposal) and the negative impacts on the receiving environment.

By reducing potable water consumption in urban areas, important economic savings can be achieved, not only for the population but also for governments. The inefficient use of water has not only negative consequences for the environment but it also represents higher energy use in treatment plants and supply systems, with extra financial and environmental costs (Santos & Taveira-Pinto 2013).

As an example of potential economic and environmental benefits of GW reuse, three houses with GW systems were studied in England. The system collected GW from the bath and bathroom washbasins and then filtered and disinfected it. Treated water was then used to flush toilets. The potable water saved ranges from 24% in a family of seven persons, up to 65% in a family of three (EA 2011). On the other hand, in a small building with 30 inhabitants, almost 300 m^3 of potable water per year can be saved by reusing GW (about 30% of the total water consumption (Santos 2012)).

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This practice gains major importance in countries suffering from severe water stress and droughts and, for this reason, governments in countries such as Australia are developing policies and on-ground actions for conserving and recycling water (Pinto *et al.* 2010). While practical guidelines for the reuse of GW for irrigation are being made available by government agencies involved in water management and regulation, there are a number of issues related to human, soil and plant health risks and environmental pollution that need further investigation to promote safe reuse. There is an urgent need to examine these issues and concerns and seek answers to specific questions and develop guidelines with local data to ensure the sustainability of GW reuse (Pinto *et al.* 2010).

However, any strategy of water reuse that involves changes in people's habits will have to achieve social acceptance to be successful (Friedler *et al.* 2006; Matos *et al.* 2013). Water reuse needs to include community and stakeholder participation from the beginning and so its public acceptance has to be assessed. Muthukumaran *et al.* (2011) concluded that community receptivity for reusing GW is highest for uses such as irrigation and flushing toilets but decreases if personal contact with GW is needed. This reveals that people are aware that GW may contain harmful substances. In fact, due to the presence of microbial agents and since in on-site systems GW is reused in close proximity to the general population, safe reuse is only possible after appropriate treatment that increases its sanitary, environmental and aesthetic quality (Friedler & Gilboa 2010). Nowadays, there are many types of GW reuse systems with significant differences in terms of their complexity. They vary from small simple systems that drain water directly to the garden without storage, to large complex systems with storage tanks also integrated with rainwater harvesting systems (EA 2011).

The importance of a correct characterization of GW lies in the assessment of its potential for direct reuse or, if not possible, the correct definition of the treatment system in order to achieve a feasible, cost-effective one. The main aspects for a correct design of the treatment unit are the site conditions and GW characteristics which are quite variable among households (Mandal *et al.* 2011). This variability is mainly due to the type of detergents used, washed goods, lifestyle of occupants and other practices followed at household levels (Pinto *et al.* 2010). When analyzing different types of buildings, other than residential dwellings, this variation can be more significant. Summarizing, it can be said that the volume and concentration of this separately collected wastewater flow depend on consumer behavior and vary according to its source (Paris & Schlapp 2010).

This article aims to contribute to the characterization of GW produced in washbasins and showers in domestic and public buildings. As it is believed that human behavior or activities influence GW quality and quantity, it is expected that GW collected in domestic buildings should be different from that collected in public ones. A compilation of several works on GW collection and sampling produced by the authors is presented. Samples were taken from GW produced in showers and washbasins in households, changing rooms and a restaurant. Results are compared with values presented in similar studies and with standards and guidelines published in different countries in order to conclude whether it is possible to reuse it directly or after treatment.

MATERIALS AND METHODS

GW from domestic buildings

To determine GW quality in domestic buildings, independent samples were collected from eight single family houses, varying in the number of inhabitants from 2 to 6 people per house. GW was separated by its origin and samples were then collected in bathtubs and washbasins.

In each sample the following physical and chemical parameters were analyzed: pH, electrical conductivity, temperature and chemical oxygen demand (COD). All parameters, except COD, were analyzed with sensors. COD was analyzed in accordance with *Standard Methods for the Examination of Water and Wastewater* (AWWA-APHE-WPCF 1989). Total dissolved solids (TDS) concentration was calculated indirectly from the electrical conductivity value measured, using the following expression:

$$\mathrm{EC[dS/m]} \times 640 = \mathrm{TDS[mg/L]}$$

Microbiological parameters were also analyzed, namely total and fecal coliforms which were determined following standard procedures (APHA 1992).

GW from public buildings

In the public buildings, GW was collected from washbasins of a changing room exclusively used by the employees and also in a public toilet of a restaurant, both located in the Faculty of Engineering of Porto University, Portugal. Other samples of GW were collected from showers located in a changing room for the employees of a wastewater treatment plant in Vila Nova de Gaia, Portugal. The collection and sampling of GW was made on a weekly frequency.

Samples were taken, preserved and analyzed in accordance with *Standard Methods for the Examination of Water and Wastewater* (AWWA-APHE-WPCF 1989). Determined parameters included pH, Total and Volatile Suspended Solids (TSS and VSS), Total Solids (TS), Ammonia (NH3), Total Phosphorus (TP), Organic Matter (COD and BOD (biochemical oxygen demand)) and Turbidity.

Samples of GW were also analyzed for microbiological parameters, namely total and fecal coliforms, in the Microbiological Laboratory of the Faculty of Engineering of Porto University.

RESULTS AND DISCUSSION

GW quality is expected to vary widely due to different uses of sanitary installations (in this case, showers and washbasins). In the public buildings this variation should be more significant since those installations are used by diverse people and, consequently, the amount of dirtiness, soaps, bathing products and other pollutants varies accordingly with every usage.

Results obtained from the physical, chemical and microbiological analysis of GW collected in residential and public buildings are presented in Tables 1 and 2.

Results presented in Table 1 show high concentrations of solids (TSS, TDS and TS). In public buildings GW presents a much higher concentration of dissolved solids, which can be explained by a greater use of soaps when washing hands and the fact that source water may be more saline. By comparing the concentrations of solids in washbasins and showers, it can be seen that values are very similar in these two places, both in public and domestic buildings.

In washbasins the organic matter was found to be similar in domestic and public buildings; however GW from showers presents higher COD values in domestic showers than in public ones. This can be due to the quantity of

Table 1 | Physical and chemical parameters (mean and standard deviation – SD)

	Washbasins				**Baths/showers**			
Type of building	**Public**		**Domestic**		**Public**		**Domestic**	
Number of samples	**16**		**8**		**4**		**8**	
	SD	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**
pH	0.2	7.3	0.5	7.1	0.3	6.9	1.1	6.7
Conductivity (μs/cm)	–	–	21.1	100.9	–	–	42.3	94.6
TSS [mg/L]	36	74	–	–	13	58	–	–
TDS [mg/L]	100	282	–	65	194	269	–	61
VSS [mg/L]	27	64	–	–	3	43	–	–
TS [mg/L]	106	356	–	–	198	326	–	–
NH_3 [mg/L]	0.5	0.9	–	–	0.8	8.6	–	–
TP [mg/L]	0.3	0.7	–	–	0.2	1.3	–	–
COD [mg/L]	67	179	–	197	85	197	–	540
BOD [mg/L]	18	59	–	–	116	129	–	–
Turbidity (NTU)	0.3	25.1	–	–	–	–	–	–

Table 2 | Microbiological parameters

	Washbasins				**Baths/showers**			
Type of building	**Public**		**Domestic**		**Public**		**Domestic**	
Number of samples	**6**		**8**		**1**		**8**	
	SD	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**
Fecal coliforms (cfu/100 mL)	0	0	5.2E + 02	3.3E + 02	0	0	6.0E + 04	4.5E + 04
Total coliforms (cfu/100 mL)	2.3E + 07	3.5E + 07	3.5E + 04	5.4E + 04	0	0	1.1E + 05	2.2E + 05
Fecal streptococci (cfu/100 mL)	1.9E + 03	2.6E + 03	–	–	–	–	–	–
Pseudomonas aeruginosa (cfu/100 mL)	0	0	–	–	–	–	–	–

soaps used in domestic showers. On the other hand, the tendency of taking longer showers in public buildings, once there is no worry about the cost of water, leads to a more diluted GW, and thus to lower concentrations.

The variation of pH and total phosphorus is not significant in the different uses and buildings studied. However, higher concentrations of ammonia and BOD were registered in samples from showers, probably due to the existence of urine.

Microbiological contamination, in terms of fecal coliforms is very elevated in domestic buildings but surprisingly it was not found in washbasins and showers in the public buildings. This may be explained by the possible presence of young children, using diapers, in domestic buildings. The diaper change is a process that can imply some contamination with fecal coliforms. On the other hand, total coliforms were found in GW from washbasins in both types of buildings, and were higher in the public buildings. The washing temperature in washbasins is generally not very high and so total coliforms may be resistant to the environment and even reproduce (Gilboa & Friedler 2008). Public buildings may generally have a higher contamination in total coliform rates than domestic buildings due to the fact that the temperature used in washbasins in public buildings is generally lower than in domestic ones.

Another interesting result is that even though there were many total coliforms in the public buildings, none of them were fecal coliforms. This is probably due to the fact that these washbasins were either located in a dressing room mainly used for showering, or were in a restaurant, so it is expected that people who use these facilities do not use the toilets nearby very much.

Results were compared with data from similar studies undertaken in different countries and presented in Table 3.

Comparing data from Tables 1 and 2 with values from the literature (Table 3), it can be seen that:

- pH values, in general, do not vary significantly and the ones obtained in this study are similar to the references;
- electrical conductivity measured in domestic buildings is very low when compared to the references;
- values of total solids are higher than the ones presented by other authors but in this study, and also in the literature, the dissolved fraction is higher than the suspended one;
- values of ammonia are included in the range presented by Christova-Boal *et al.* (1996) and total phosphorus is lower than the values from literature;
- COD and BOD also present values that are higher than the literature but are in the range of Christova-Boal *et al.* (1996).
- microbiological parameters (fecal and total coliforms and fecal streptococci) are in the range presented by other authors.

To assess the reuse potential of the collected GW, results were also compared with the normative references and guidelines published in different countries (Table 4).

Table 3 | References of GW characteristics

References	**Paris & Schlapp (2010)**	**Mandal *et al.* (2011)**			**Merz *et al.* (2007)**		**Gilboa & Friedler (2008)**		**Christova-Boal *et al.* (1996)**	
Collecting place	**Showers, laundry, washbasins and kitchen sink**	**Bath, laundry and wash basins**			**Showers**		**Baths, showers and washbasins**		**Bathroom water**	
	Mean	**Min**	**Max**	**Mean**	**Mean**	**SD**	**Mean**	**SD**	**Min**	**Max**
pH	7.1	7.3	8.1	7.7	7.6	0.4	–	–	–	–
EC (μs/cm)	–	489.0	550.0	519.5	645.0	67.0	–	–	–	–
TSS [mg/L]	63	12	18	14.8	–	–	–	–	48	120
TDS [mg/L]	–	342	487	414.5	–	–	–	–	–	–
TS [mg/L]	5	–	–	–	2	0.5	–	–	–	–
NH_3 [mg/L]	–	–	–	–	–	–	–	–	< 0.1	15.0
TP [mg/L]	–	1.5	3.4	2.5	–	–	–	–	0.11	1.8
COD [mg/L]	208	244	284	264.0	109	33.0	148	49.0	–	–
BOD [mg/L]	151	56	100	78.0	59	13.0	95	29.0	76	200
Turbidity (NTU)	–	20.6	38.7	29.7	29	11.0	33	24.0	60	240
Fecal coliforms (cfu/100 mL)	6.6E + 05	3.7E + 04	3.8E + 04	3.8E + 04	1.4E + 05	1.1E + 05	3.8E + 04	9.3E + 04	1.7E + 02	3.3E + 03
Total coliforms (cfu/100 mL)	4.7E + 07	3.5E + 04	3.6E + 04	3.5E + 04	–	–	–	–	5.0E + 02	2.4E + 07
Fecal streptococci (cfu/100 mL)	–	–	–	–	–	–	–	–	79	2.4E + 03
Pseudomonas aeruginosa (cfu/100 mL)	–	–	–	–	–	–	3.3E + 03	3.1E + 03	–	–

Table 4 | Water quality parameters for urban reuse

References	**Portugal (ANQIP 2011)**		**Germany (FBR 2005)**	**UK (BSI 2010)**				**USA (US EPA 2004)**
Application	**A, B**	**C, D**	**A, B**	**C**	**A**	**D**	**B**	**A to D**
pH	–	–	–	5 – 9.5	5 – 9.5	5 – 9.5	5 – 9.5	6 – 9
TSS [mg/L]	10	10	–	–	–	–	–	–
TDS [mg/L]	–	–	–	–	–	–	–	500–2,000*
BOD [mg/L]	–	–	–	–	–	–	–	≤ 10
Turbidity (NTU)	2	2	–	< 10	< 10	–	< 10	≤ 2
Fecal coliforms (cfu/100 mL)	1,000	200	< 10/mL	–	–	–	–	None detectable
Total coliforms (cfu/100 mL)	10,000	10,000	< 100/mL	10	1,000	1,000	10	–
Fecal streptococci (cfu/100 mL)	–	100	–	–	–	–	–	–
Pseudomonas aeruginosa	1 cfu/mL	–	–	–	–	–	–	< 1 cfu/mL

A – Toilet flushing, B – Laundry, C – Spray application (pressure washing, garden sprinkler and car washing), D – Garden watering (non spray).

* Only for irrigation.

Comparing the obtained results (Tables 1 and 2) with the limit values presented in Table 4 it is possible to conclude that GW has to be treated prior to its reuse. Although parameters such as pH and TDS are in accordance with the presented limits, TSS and organic matter (measured by BOD) are too high.

Microbiological parameters are also out of the recommended range both in domestic and public buildings, indicating that there has to be a disinfection of GW prior to reuse.

A GW treatment unit is important not only to guarantee a safe reuse, in terms of public health, but also to assure the proper functioning of the piping system and all the supplied equipment that can be damaged by the accumulation of solids, for example, and formation of biofilm. Both in domestic and public buildings, GW must not be stored for too long since the existing nutrients, organic matter and high temperatures are ideal conditions for bacterial growth. Because of this, it is recommended that reuse should occur only a few hours after GW is collected.

More standards or legislation must be published in this area, for example in the European Union, to define the limits for quality parameters of non-potable water use. Public buildings showed high microbiological contamination (Table 2) so, even after treatment, reuse should only be possible for purposes with no human contact (sprinkler irrigation with treated GW should not be allowed). Management teams must be responsible for monitoring treated GW frequently, and this type of monitoring, including sampling frequency and controlling parameters, must also be presented in standards or legislation.

In domestic buildings, inhabitants should be responsible for the treatment system and the type of uses where non-potable water is consumed. When human contact may occur, inhabitants must be encouraged to frequently monitor their treated GW quality. To support this practice, governments must provide user-friendly information packages and educational programs to inform the population about the advantages of this practice, its risks and to encourage the installation of safe GW reuse systems.

On the other hand, GW reuse systems must be carefully studied and designed in order to maximize the benefits to users and guarantee their safety. When designing and installing these systems, it is very important to take some care to avoid cross connections and the contamination of the potable water supply network, for example by clearly identifying non-potable supply systems. In public buildings, these systems must be frequently inspected, especially in places where the risk of potable contamination is higher, such as the non-potable reservoir and its potable back-up supply.

CONCLUSIONS

This study shows that GW quality varies significantly in public and domestic buildings. Different uses made of sanitary installations, the existence of young children, the amount of dirtiness, soaps and bathing products, the temperature in washbasins, and the time spent in the shower are the main factors that explain the different values obtained in domestic and public buildings, especially in terms of dissolved solids, COD and microbiological contamination.

Results of GW quality obtained in this study are comparable with similar studies, but do not comply with limit values defined in standards and guidelines from Portugal, Germany, UK and USA. Although parameters such as pH and TDS are in accordance with the presented limits, TSS and organic matter are too high. Microbiological parameters are also out of the recommended range both in domestic and public buildings, indicating that GW must be disinfected prior to its reuse.

GW characteristics presented in this study confirm that it is important to develop and optimize GW treatment systems and make them safe and effective for specific non-potable uses, in order to promote further development and a large scale integration of GW reuse in urban areas. Both in public and domestic buildings it can be seen that GW needs treatment which must be defined considering the reuse purposes, and the risk exposure of the population.

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