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Greywater Use in Irrigation: Characteristics, Advantages and Concerns

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1. Introduction

Agriculture and urban irrigation import large volumes of clean water to provide for the water needs. The shortage of freshwater resources is an ever-increasing concern worldwide, particularly in the Middle East and North Africa, where the availability of water is reaching crisis levels and chronic water stress (Jury & Vaux Jr, 2007). The awareness of the natural limitations of this resource is growing and so, water reuse has assumed a great significance. In some countries, like Israel, 70% of the treated wastewater is reused for agriculture irrigation (Mekorot, 2007).

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%). According to Melo-Baptista, (2002), 87.3% of the volume of water used in Portugal is for agriculture and 91.9% of this volume is inefficiently used which represents 219M€/year.

The amount of water needed for domestic consumption in developed countries is around 100-180 L/hab.dia, representing 30-70% of the amount of water required in an urban area (Friedler, 2004). The increased demand for water leads to demand for new more distant sources and / or greater depths, which leads to increased environmental costs and economic exploitation. Within this context, new approaches are emerging to achieve a more sensible and sustainable management of existing water researches. In fact, to avoid the deterioration of this situation it is imperative to consider different approaches such as water reuse strategies. Indeed, one of ways by which we can reduce the pressure on town water supplies is to reuse greywater for irrigation around household. The use of domestic greywater for irrigation is becoming increasingly common in both developed and developing countries to cope with the water scarcity. The adoption of this and other measures will lead, in Portugal, to the increase of efficiency in the use of water, in agriculture, what will allow savings of 65 M€/year (Melo-Baptista, 2002).

The use of decentralise, alternative water sources such as rainwater or greywater is increasingly promoted worldwide.

2. Greywater reuse

Wastewater reuse in agriculture, after the appropriate treatment, may be a high advantageous technique, once that these wastewaters are very rich in organic matter and nutrients that can be used by the cultures and soils. Wastewater reuse in agriculture, design as "Blackwaters farming" is referenced since the final of XIX century in countries like Australia, France, Germany, India, United Kingdom and USA. In the last 20 years it is observed a growing interest in the use of these wastewaters in irrigation, mainly in the arid and semi-arid regions, where is found a lack of water and a grown need for food production (WHO, 1989).

The water becomes, inside houses, in two types of wastewater, black water and greywater, which is centralized in a single collector mixture towards a system of single treatment. Greywater is defined as the domestic wastewater without the contribution of black water from the toilets, i.e., corresponds to the wastewater from baths, washbasins, bidets, washing machines and dishwashers and kitchen sink (Eriksson et al., 2002). Greywater is usually considered to be high volume with a lower level of pollution while blackwater is low volume with the higher level of pollution (Neal, 1996).

A greywater use system captures this water before it reaches the sewer. Kitchen sink or dishwasher wastewater is not generally collected for use as it has high levels of contamination from detergents, fats and food waste, making filtering and treatment difficult and costly (Matos, 2009). This separation allows creating a light greywater (LGW) for use. So, LGW exclude water from the washing machine, dishwasher and kitchen sink.

Wastewater and greywater recycling are emerging as integral part of water demand management, promoting the preservation of high quality freshwater as well as reducing pollutants in the environment and reducing overall supply costs (Al-Jayyousi, 2003). Recent developments in technology and changes in attitudes towards water reuse suggest that there is potential for greywater reuse in the developing world.

It is estimated that the total amount of greywater corresponds to 50-80% (Hansen & Kjellerup, 1994; Al-Jayyousi, 2003) of the wastewater drained from a house constituting the largest potential source of water saving, if consider the possibility of reuse. Greywater is therefore an important component of wastewater and, qualitatively, studies have shown that there is a significant contribution of this greywater to the concentration of some pollutants and contaminants in the total wastewater. In fact, despite being regarded by many as relatively clean water, greywater can be quite polluted, and its indiscriminate use may represent a risk to public health.

The reuse of greywater *in situ*, may prove to be a practice to consider since its quantity and quality is sufficient to meet the demand for some urban non-potable purposes, such as toilet-flushing, cars-washing and irrigation, since the amount of water required is high and the quality may be lower than the drinking-water.

2.1 Greywater characteristics

2.1.1 Quality parameters

Although conceived to be clean, greywater is polluted and contaminated. Greywater contributes significantly to wastewaters parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonium (NH_4^+), total phosphorous, boron, metals, salts, surfactants, synthetic chemicals, oils and greases, xenobiotic substances, and microorganisms (Friedler, 2004; Wiel-Shafran et al., 2006; Travis et al., 2008; Eriksson et al., 2002; Gross et al., 2007; Eriksson & Donner, 2009). Untreated domestic wastewater typically contains 50 to 100 mg/L of oils and greases with approximately 2/3 of the load contributed by greywater (Gray & Becker, 2002;

Tchobanoglous et al., 2003). All of these components have potential negative environmental and health impacts.

There is some research on the quality of greywater and its variation by source (Tables 1 and 2) and within source type (Matos, 2009; Matos et al., 2010). For instance, literature reports important differences for washing machines between the effluents of different cycles and the same can be expected from dishwashers (Rose et al., 1991; Burrows et al., 1991; Christova-Boal et al., 1996; Surendan& Wheatley, 1998; Shin et al., 1998; Nolde, 1999; Eriksson et al., 2002; Friedler, 2004).

Parameters	WC	Bath	Hand-wash	Kitchen sink	Washing machine	Dishwasher
Turbidity (NTU)	60-240[1]	92[2] 28-96[3] 49-69[4]	102*[2]		50-210[1] 108[2] 14-296[3]	
Total solids (mg/L)		631[2] 777-1090[5] 250[6]	558[2] 835[5]	1272-2410[5] 2410[6]	658[2] 350-2091[5] 410-1340[6]	45-2810[5] 1500[6]
Total volatile solids, TVS (mg/L)		318[2] 533[5] 190[6]	240[2] 316*[5]	661-720[5] 1710[6]	330[2] 125-765[5] 180-520[6]	30-1045[5] 870[6]
Total suspended solids, TSS (mg/L)	48-120[1]	76[2] 54-303[5] 120[6] 54-200[7]	40[2] 259[5] 181[7]	625-720[5] 720[6] 185[8]	88-250[1] 68[2] 65-280[5] 120-280[6] 165[7]	15-525[5] 440[6] 235[7]
Volatile suspended solids, VSS (mg/L)		102[5] 85[6] 9-153[7]	36-86[5] 72[7]	459-670[5] 670[6]	97-106[5] 69-170[6] 97[7]	10-424[5] 370[6]
pH	6.4-8.1[1] 7.1[5]	7.6[2] 6.7-7.4[4,5]	8.1[2] 7.0-8.1[5]	6.5[5] 6.3-7.4[8]	9.3-10.0[1] 8.1[2] 7.5-10.0[5]	9.3-10.0[1]
Chemical oxygen demand, COD (mg/L) Total	210-230[5]	645[5] 210-501[7] 100-633[9] 282[10]	95-386[5] 298[7] 383[10]	936[2] 644-1340[5] 1079[7] 1380[10] 15-26[11]	725[2,10] 1339[5] 1815[7]	1296*[5]
Dissolved	165[5]	319[5] 184-221[7]	270[5] 221[7]	679*[5] 644[7]	996[5] 1164[7]	547*[5]
Biochemical oxygen demand, BOD_5 (mg/L) Total	173[5]	216[2] 170[6] 424[5] 192[10]	252[2] 33-236[5] 236[10]	536[2] 1460[6] 530-1450[5] 5[8] 2762[10]	48-290[1] 472[2] 280-470[5] 150-380[6] 282 [10]	390-699*[5] 1040[5]

Dissolved	76-200[1] 75[5]	237[5]	93*[5]	377*[5]	48-290[1] 381*[5]	262*[5]
Total organic carbon, TOC (mg/L) Total	91[5]	104[2] 30-120[5] 100[6]	40[2] 119[5]	582*[5] 880[6]	381[5] 100-280[6]	234*[5] 600[6]
Dissolved	47[1]	59[5]	74*[5]	316*[5]	281*[5]	150*[5]
Nitrogen (mg/L) Total	4.6-20[1]	17[6] 5-10[9]		74[6] 15.4-42.5[8]	1-40[1] 6-21[6]	40[6]
Ammonia	<0.1-15[1] <0.9-1.1[5]	1.6[2] 0.1-0.4[3] 1.2[5] 2[6] 1.1-1.2[7] 1.3[10]	0.5[2] 0.4-1.2[5] 0.3[7] 1.2[10]	4.6[2] 0.6-6.0[5] 6.0[6] 0.3[7] 0.2-23.0[8] 5.4[10]	<0.1-0.9[1] 10.7[2] 0.06-3.5[3] 4.9-11.0[5] 0.4-0.7[6] 2.0 [7] 11.3[10]	4.5-5.4[5] 4.5[6]
Nitrates and Nitrites	<0.05-0.2[1]	0.9[2] 0.4[6] 4.2-6.3[7] 0.4[10]	0.3[2] 6.0[7] 0.3[10]	0.5[2] 5.8[3] 0.3[6] 0.6[10]	0.1-0.3[1] 1.6[2] 0.4-0.6[6] 2.0 [7] 1.3[10]	0.3[6]
Phosphorus (mg/L) Total	0.11-1.8[1]	2.0[6] 0.2-0.6[10]		74.0[6]	0.06-42[1] 21-57[6]	68[6]
Phosphates	4.6-5.3[5]	1.6[2] 10-19[5] 1.0[6] 5.3-19.2[7] 0.9[10]	45.5[2] 13-49[5] 13.3[7] 48.8[10]	15.6[2] 13-31 [5] 31.0[6] 26.0[7] 0.4-4.7[8] 12.7[10]	101.0[2] 4-170[5] 4-15 [6] 21.0[7] 171.0[10]	32-537[5] 32.0[6]

Table 1. Values for physical-chemical parameters and nutrients in greywater.*Mean of 150 samples; [1] Christova-Boal et al. (1996); [2] Surendran& Wheatley (1998); [3] Rose et al. (1991); [4] Burrows et al. (1991); [5] Friedler (2004); [6] Siegrist et al. (1976); [7] Almeida et al. (1999); [8] Shin et al. (1998); [9] Nolde (1999); [10] Laak (1974) ; [11] Hargelius et al. (1995).

Laundry greywater exhibited a high range of the values of suspended solids, salts, nutrients, organic matter and pathogens which arise from washing of clothes using detergents (Christova-Boal et al., 1996). In fact, some activities such as washing faecal contaminated laundry, childcare and showering add faecal contamination to greywater (Ottoson & Stenström, 2003). Occasionally, gastrointestinal bacteria such as *Salmonella* and *Campylobacter* can be introduced by food-handling in the kitchen (Cogan et al., 1999). Greywater may have an elevated load of easily degraded organic material, which may favour growth of enteric bacteria such as faecal indicators and such growth as been reported in wastewater systems (Marville et al., 2001).

Kitchen greywater is reported as the highest contributor of oils and greases in domestic greywater, but oils and greases are present in all greywater streams (Friedler, 2004).

As demonstrated, the chemical, physical and microbiological characteristics of greywater are quite inconstant among households due to the type of detergents used, type of things being washed, life style of occupants and other practise followed at household levels.

Parameters	Kitchen	Laundry	Bathroom
Escherichia coli (number/100 mL)	$1.3 \times 10^5 - 2.5 \times 10^8$ (1)		
Thermotolerant *E. coli*	$9.4 \times 10^4 - 3.8 \times 10^8$ (1)		
Faecal Streptococcus	$5.1 \times 10^3 - 5.5 \times 10^8$ (1)	MPN 23 - < 2.4×10^3 (2) $1 - 1.3 \times 10^6$ (3)	MPN 79 - 2.4×10^3 (2) $1.0 \times 10^4 - 7.0 \times 10^6$ (3)
Total Coliforms	$6.0 \times 10^4 - 4.0 \times 10^7$ (1)	MPN $2.3 \times 10^3 - 3.3 \times 10^5$ (2) $8.5 \times 10^5 - 8.9 \times 10^5$ (3) 7.0×10^5 (4)	MPN 500 - 2.4×10^7 (2) $8.2 \times 10^3 - 7.0 \times 10^4$ (3) $5.0 \times 10^4 - 6.0 \times 10^6$ (4)
Faecal Coliforms		MPN 110- 1.09×10^3 (2)	MPN 170 - 3.3×10^3 (2) $1.0 \times 10^3 - 2.5 \times 10^3$ (3) $6.0 \times 10^2 - 3.2 \times 10^3$ (4)

Table 2. Range values for microbial parameters analyses in greywaters obtained in kitchen, laundry and bathroom. (1) Günther (2000); (2) Christova-Boal et al. (1996); (3) Siegrist et al. (1976); (4) Surendran&Wheatley (1998). MPN: most probable number .

2.1.2 Quantity parameters

The amount of wastewater generated within a house varies greatly and depends on several factors such as the age and number of occupants, their habits and how they use water. Some European cities can reach to 586 L/ day / fire of wastewater generated. According to NSW (2006) greywater accounts for 68% (Figure 1) of the total wastewater generated mainly composed of baths and showers (49%) and laundry (34%).

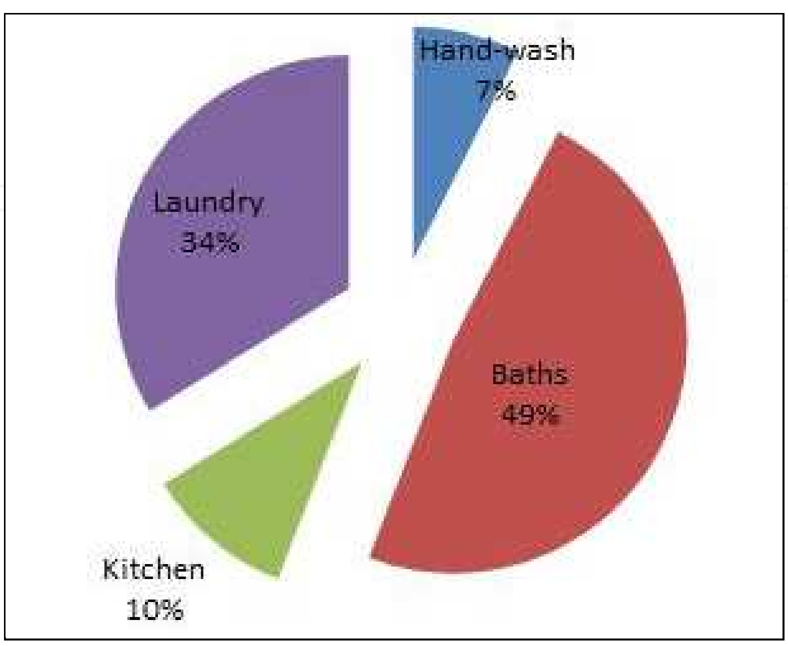


Fig. 1. Distribution (in percentage) of greywater generated in a house (NSW, 2006).

The expression of these quantities in liters per day, based on the reference value to European capitals, has a distribution represented in Figure 2. The differential for the 586 L / day is spent in the toilets.

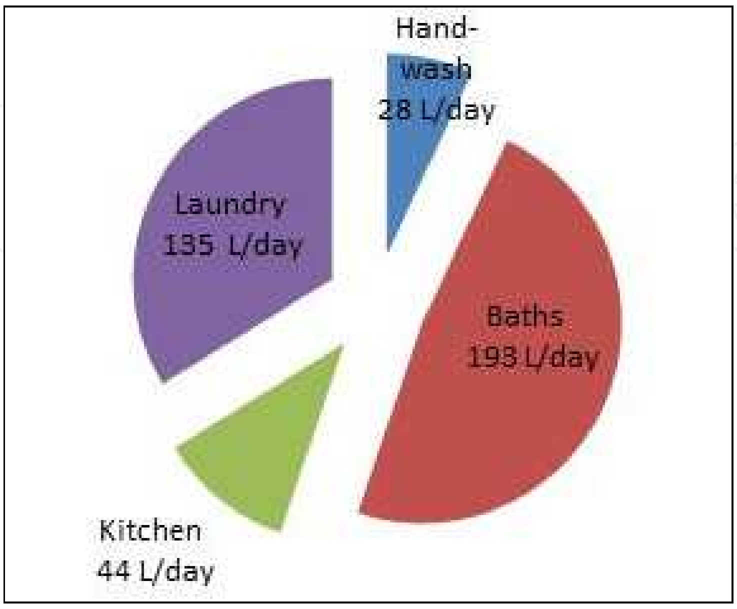


Fig. 2. Distribution of greywater generated in a house in L/day (NSW, 2006).

The capitation varies from country to country. Referring to the example of Israel, Friedler et al. (2005) suggest a capitation from 100 to 150 L/hab.day. In Portugal, it is estimated that each inhabitant spends between 100-180 L/day of water.

Depending on the type of reuse that is considered, all the studies agree on the fact that greywater generated in a house is more than enough to supply inside needs. Friedler, (2004) refers that a greywater reuse scheme would consume only 50-65% of the total greywater produced. Toilet flushing, washing of pavements and cars, and garden irrigation are uses in which the quantity of greywater dispended is high and the needs in terms of quality can be lower than the potable water, and so these can represent potential reuse applications in a unfamiliar dwelling.

Studies that examined the potential of greywater reuse to save freshwater supplies reported savings in the range of 30-50% when greywater is reused for toilet flushing and irrigation (Jeppesen, 1996). When greywater is reused, particularly in garden irrigation considerable volumes of high quality water can be saved.

2.2 Greywater reuse in irrigation

One commonly applied individual initiative to reuse wastewater is the recycling of greywater specifically for irrigation (Travis et al., 2010). In fact, in the past years greywater reuse for irrigation has been considered as a mean of water conservation, since represents the largest potential source of water and costs savings in domestic residence (Al-Jayyousi, 2003), savings up to 38% of water when combined with sensible garden design.

Greywater is a potentially reusable water resource for irrigation of household lawns and gardens (Al-Jayyousi, 2003) as diversion of laundry effluent. According to Jeppesen, (1996) this is technically possible without treatment.

2.2.1 Quality requirements

According to Nolde & Dott (1991), greywater for recycling should accomplish four criteria: hygienic safety, aesthetics, environmental tolerance and technical and economic feasibility.

Important parameters to consider for the sustainability of greywater reuse are pH, electrical conductivity, suspended solids, heavy metals, faecal coliforms, *Escherichia coli*, dissolved oxygen, biological and chemical oxygen demands, total nitrogen and total phosphorus (Dixon et al, 1999; Birks & Hills, 2007; Eriksson et al, 2002).

Reuse of greywater for growing plants may affect the microbial activity in the rizosphere that degrades the surfactants and the use by plant for transpiration (Garland et al., 2000). Also, greywater has the potential to increase the soil alkalinity if applied on garden beds over a long time. Greywater with pH values higher than 8 can lead to increase soil pH and reduce availability of some micronutrients for plants.

The various parameter values for the treated wastewater to meet depend on the type of reuse that is proposed. WHO (2006) sets standards in their values of microbiological parameters (Table 4) due to irrigation with wastewater. EPA has already published some guidelines on the reuse of treated domestic wastewater in a variety of purposes, such as agricultural reuse (edible and non-edible crops), urban reuse, and irrigation in areas with restricted access, reuse for recreational purposes, the reuse in construction, environmental reuse, industrial reuse, groundwater recharge and indirect potable reuse.

EPA (2004) classifies agricultural reuse in two subtypes: the reuse by crops not industrially processed and crops industrially processed/non-comestible. In Table 3 there are exposed the quality criteria. The mainly differences relies on admissible BOD and faecal coliforms values, higher in irrigation crops industrially processed.

Parameters	Crops not industrially processed	Crops industrially processed Crops non-comestible
pH	6.9 – 9.0	6.9 – 9.0
BOD (mg/L)	10.0	30.0
Turbidity (NDU)	2.0	n.r.
TSS (mg/L)	n.r.	30.0
Faecal coliform (CFU/100 mL)	Not detectable	< 200
Residual chlorine (mg/L)	1.0	1.0

Table 3. Quality criteria required for agricultural reuse (EPA, 2004). BOD- Biological Oxygen Demand - Standardmethod for indirect measurement of the amount of organic pollution (that can be oxidized biologically) in a sample of water; TSS – Total Suspended Solids - refers to the identical measurement: the dry-weight of particles trapped by a filter, typically of a specified pore size.; n.r. – no reference

WHO divides its criteria in restricted areas of irrigation, that is not accessible, and non-restricted areas. As excepted the criteria are less demanding in the second case.

Parameters	Crops not industrially processed	Crops industrially processed Crops non-comestible
Helminths eggs (n/L)	< 1	< 1
E. coli (CFU/100 mL)	10^5	10^3

Table 4. Microbial quality criteria required for accessible and restricted irrigation areas (WHO, 2006).

According to the NP 4344 concentrations in the wastewater of different elements that constitute a potential risk to the environment should not be higher than the corresponding maximum recommended value (VMR) referred in Decree-law No. 236/98 of 1 August. The physical-chemical parameters referred in Decree-Law as limiting the quality of irrigation water (pH, salinity, sodium absorption ratio, and TSS) should not also exceed the values referenced in Table 5.

	Water quality for irrigation			**Water quality for irrigation**	
Parameters	RMV	AMV	Parameters	RMV	AMV
Al	5.0	20.0	Mn	0.2	10.0
As	0.10	10.0	Mo	0.005	0.05
Ba	1.0	-	Ni	0.5	2.0
Be	0.5	1.0	NO_3^-	5.0	2.0
B	0.3	0.75	SAR	8.0	-
Cd	0.01	0.05	Salinity (dS/m)	1.0	-
Pb	5.0	20.0	TDS (mg/L)	640	-
Cl^-	70.0	-	Se	0.02	0.05
Co	0.05	10.0	TSS (mg/L)	60	-
Cu	0.20	5.0	SO_4^{2-}	575	-
Cr	0.10	20.0	V	0.10	1.0
Sn	2.0	-	Zn	2.0	10.0
Fe	5.0	-	pH	6.5 – 8.4	4.5 – 9.0
F	1.0	15.0	Faecal coliform (CFU/100 mL)	100	-
Li	2.5	5.5	Helminths eggs (n/L)	n.d	1

Table 5. Recommended maximum value (RMV) and Admissible maximum value (AMV) in accordance with Decree-law No. 236/98 (Portugal). Units are in ppm, except when otherwise noted. Sodium Absorption Reason – SAR; Total Dissolved Solids – TDS; Total Suspended Solids – TSS; n.d. – not detectable.

2.2.2 Treatment requirements

Large scale wastewater irrigation programs typically are preceded by conventional treatment measures. However, when wastewater or greywater is reused on the household or in a small property scale, whether due to lack of centralized treatment options or homeowner initiative to save water, adequate treatment is often lacking (Wiel-Shafran et al., 2006).

It is a frequent misconception that greywater is cleaner than combined wastewater and therefore can be reused with minimal or without treatment (Gross et al., 2007). Contrary to public perception, many recent investigations highlight the necessity of greywater treatment before its use on irrigation (Friedler & Gilboa, (2010)).

According to Friedler & Gilboa, (2010), since in on-site systems greywater is reused in close proximity to the general population, safe reuse is possible only after an appropriate treatment that increases its sanitary, environmental and aesthetic quality, which leads to the generally accepted need to provide effective disinfection prior to reuse.

Greywater is often extensively treated in combined systems or separately in spread settlings. The later treatment often consists of a settling tank followed by a soil infiltration system, a sandfilter trench or a subsurface flow wetland providing a reduction of coliforms (Strenström, 1985). The high-grade treatment of greywater has been questioned since it constitutes, as said, a large fraction of the actual wastewater flow, but has a low degree of faecal contamination (Jackson & Ord, 2000) and local systems are often ill adapted for reuse.

Al-Jayyousi (2003) described the most common greywater technologies, which divided in Basic two stage systems and biological systems. The first one consists generally in a coarse filtration (thought fibrous of granular depth, or membranes filters) plus disinfection (chlorine or bromine), that employs a short residence time so that the chemical nature of greywater remains unaltered and only minimal treatment is required. The second one involves membrane bioreactors (MBR) and biologically aerated filters (BAF). An alternative approach to disinfection with chlorine is using UV radiation with great results (Friedler & Gilboa, 2010).

According to EPA (2004), the wastewater suitable for irrigation of crops that will not be industrially processed, must go through a secondary treatment, followed by filtration and disinfection. The wastewater suitable for irrigation of crops industrially processed must pass through secondary treatment followed by disinfection.

With regard to the irrigation of non-processed crops, or irrigation of pastures, fields of cereals and other crops not intended for direct consumption, wastewater will have to pass by a secondary treatment, followed by filtration and disinfection, as well as for non-processed crops processed industrially.

2.2.3 Advantages and disadvantages

Below are listed some reported negative effects about greywater irrigation:

- Development of soil hydrophobicity (Chen et al., 2003; Tarchitzky et al., 2007; Wallach et al., 2005);
- Reduction of soil hydraulic conductivity by the surfactants or food-based oils (Travis et al., 2008);
- Surfactants are, as said, a class of synthetic compounds commonly found in greywater and a significant accumulation of these compounds in soils, may ultimately lead to water repellent soils with adverse impacts on agricultural productivity and environmental sustainability (Shafran et al., 2005; Wiel-Shafran et al., 2006);
- Increase of pH in soils and reduced availability of some micronutrients for plants (Christova-Boal et al., 1996);
- Substantial reduction in transpiration rate when pH is above 9 (Eriksson et al., 2006);
- Possibilities of accumulation of sodium and boron in soil, that affects soil properties and plant growth adversely (Misra & Sivongxay, 2009; Gross et al., 2005); Soil aggregate dispersion from sodium accumulation (Misra&Sivongxay, 2009);
- Phytotoxicity due to anionic surfactant content that alters the microbial communities associated with rhizosphere (Eriksson et al., 2006)
- Microbialrisks (Gross et al., 2007);
- Enhanced contamination transport (Grabber et al., 2001);

Sequentially are described some reported positive effects of greywater irrigation:

- Misra et al., (2010) suggested that laundry greywater has a promising potential for reuse as irrigation water to grow tomato, once that compared with tap water irrigated plants, greywater irrigated plants substantially uptake greater quantity of Na (83%) and Fe (86%);
- As said, a large proportion of the ingredients of laundry detergents are essentially non-volatile compounds dominated salts, some of them can be beneficial to plants,

particularly nutrients, although a balanced concentration is required to avoid nutrient deficiency or toxicity in plants (Misra et al., 2010).

- Important water savings and resulting environmental benefits.

2.2.4 Legal aspects

In most countries, until a few years ago, there were no specific guidelines and quality standards for assessing the potential reuse of greywater and associated risks. Legal issues based on alternative related regulations or national discharge limit values, defined for other discharge reuse applications, but not specifically for greywater.

The assessment of water quality until the mid-twentieth century was made based on their aesthetical and organoleptic properties (visual appearance, taste and smell). However, with the progress of science and knowledge, has been coming to the conclusion that this evaluation was insufficient to meet the minimum requirements to protect public health. It has become extremely important to establish normative values for certain parameters that could injury public health.

The World Health Organization (WHO) is a pioneer in defining these values, with the publication of water quality standards, whose first version appeared in the 50's, suffering multiple updates up to today. These standards were the basis for creation in many countries of their own laws. In 1989 the WHO launched a first draft of "Wastewater use in agriculture: guidelines for the use of wastewater excreta and greywater," revised in 2002 and published in 2006. The document, which refers only to the microbiological criteria, should be used for the development of international and national regulations that will assist the management of public health risk associated with the use of wastewater in agriculture and aquaculture.

The development of programs for the use of wastewater began in the twentieth century. The state of California was a pioneer in these programs and appeared in the USA, two statutes that have and continue to have a significant impact on the quantity and quality of wastewater discharged as well as its potential for reuse. These two statutes are called "Water Pollution Control Act" or "Clean Water Act" and "Safe Drinking Water Act". As a result of this law, the centralized WWTP have become common in urban areas, constituting sources of water available for reuse.

The purpose of the "Safe Drinking Water Act" was to ensure that water systems comply with the minimum requirements to protect public health. This allowed the standardization of water quality in the U.S., identifying key contaminants and their maximum limits and indirectly affected the quality of wastewater since the water courses for discharge are often the sources of water supply.

In 1992, the US Environmental Protection Agency (EPA) published "Guidelines for water quality" that describes the treatment stages, water quality requirements and monitoring tools.

Later, on 2004, EPA published the "Guidelines for Water Reuse", establishing the nature and extent of treatment and the water quality parameters to impose so that it can be reused. This document also provides some guidelines for monitoring a system for reuse.

The European Union (EU) has published two Directives on the assessment of water quality (Directive 80/778/EEC repealed by Directive 98/83/EC) and Portugal transposed these directives to the internal law, by Decree-Law No. 243/01 of September 5, setting standards for the quality of water for human consumption. Decree-Law 152/97 of 19 June regulates the criteria for collection, treatment and discharge of urban waste water into the aquatic environment. Decree-Law No. 236/98 regulating the quality of water intended for human consumption and is intended to protect public health from the adverse effects of contamination of water.

Directive 91/271/EEC states that the treated wastewater should be reused whenever appropriate and that disposal sites should minimize the adverse environmental effects. The European Commission proposed environmental quality standards that may be used as surrogates for greywater quality assessment in some countries like Portugal (Directive 2000/60/EC, 2006).

In general, the practice precedes the creation of laws. Generally only when there are problems associated with the practice emerge the need for a legal framework. Thus, in Portugal, the legislation directly incident on the field of water reuse is not yet well developed.

The RGAAR approved by Decree No. 23/95 of August 23 addresses the reuse of wastewater very superficially, in particular in Art 11 - Reuse, saying "The treated wastewater and sludge should be reused whenever possible or appropriate."

Marecos do Monte (2008 b), argues that the use of treated wastewater for irrigation, as in Portugal is of great importance, which stems the need for the existence of a standard on this subject that has been published in 2005, the Portuguese Standard NP 4434, "Standard for reuse of treated wastewater for irrigation." This standard represents an important contribution to sustainable practice of reuse of treated wastewater for irrigation, defining:

- Quality requirements for the use of urban treated wastewater as irrigation water;
- The following criteria in the selection of irrigation equipment and processes;
- The procedures to adopt in the implementation of irrigation to ensure the protection of public health and the environment;
- The procedures for the environmental monitoring of the area potentially affected by the irrigation.

The guidelines only applies to the reuse of urban treated wastewater in Wastewater Treatment Plant, in irrigation of agricultural crops, forestry, ornamental ponds, lawns and other green spaces (Marecos do Monte, 2008; Moura et al., 2006).

Despite the normative documents apply to the reuse of urban treated wastewater, these can be used as a basis for guidance on the reuse of treated greywater.

3. Case study: Greywater for irrigation *in situ*

3.1 Introduction

The qualitative and quantitative characterization of the effluent is a key aspect when trying to reuse water. The purpose of this section of the chapter is to characterise, qualitatively and quantitatively, the greywater generated in houses, in order to determine the best treatment and to evaluate the possibility of *in situ* reuse for irrigation.

As it is assumed that the water from the toilets contains high concentrations of contaminants and pollutants, they were eliminated as well as its possibility of reuse. Indeed the aim is to reuse the water by an economically viable process, which would imply the use of untreated wastewater, if possible, or, with a simple/cheap treatment. Therefore it was analyzed the total greywater (TGW), which includes water from all units except the toilet, the light greywater (LGW), that excludes dishwashers, washing machine and kitchen sink from the previous and greywater per domestic device, in order to ascertain what type of water has better features.

With this characterization, it will be possible to outline a feasible reuse strategy using only the greywater of better quality, i.e., excluding the waters from the most polluting sanitary

appliances. It is worth noting say that, the statistical significance of this characterization is limited, since the variability associated with these data is very large (Friedler & Butler, 1996).
In order to reuse it is necessary to know the quality and the quantity of greywater. In fact, to face the possibility of reuse, it is necessary to know the amount of greywater produced by each domestic device.

3.2 Methodology

3.2.1 Greywater characterization: Quality and quantity

3.2.1.1 Total greywater and light greywater quality

In order to characterize total greywater (TGW) produced in households, in the year of 2008, it was changed the drainage system of a dwelling located in Quinta da Casa Nova in Sabrosa, Vila Real District, in Tras-os-Montes and Alto Douro region, northern Portugal (Fig.3). For that purpose, was collect the greywater that came from a bathroom, comprising bath, toilet and bidet, the greywater that came from the kitchen, constituted by the kitchen sink and dishwasher and the greywater from the laundry draining the water generated by the washing machine. The daily occupancy of housing was 4 to 6 people. These wastewaters were sent to a tank in stainless steel AISI 316L, 318 L capacity. The tank capacity was provided in order to collect all the greywater generated during a day, ensuring thus the homogenization of water from various appliances.

Fig. 3. Sabrosa Location.

These are illustrated in Fig.4 and 5.

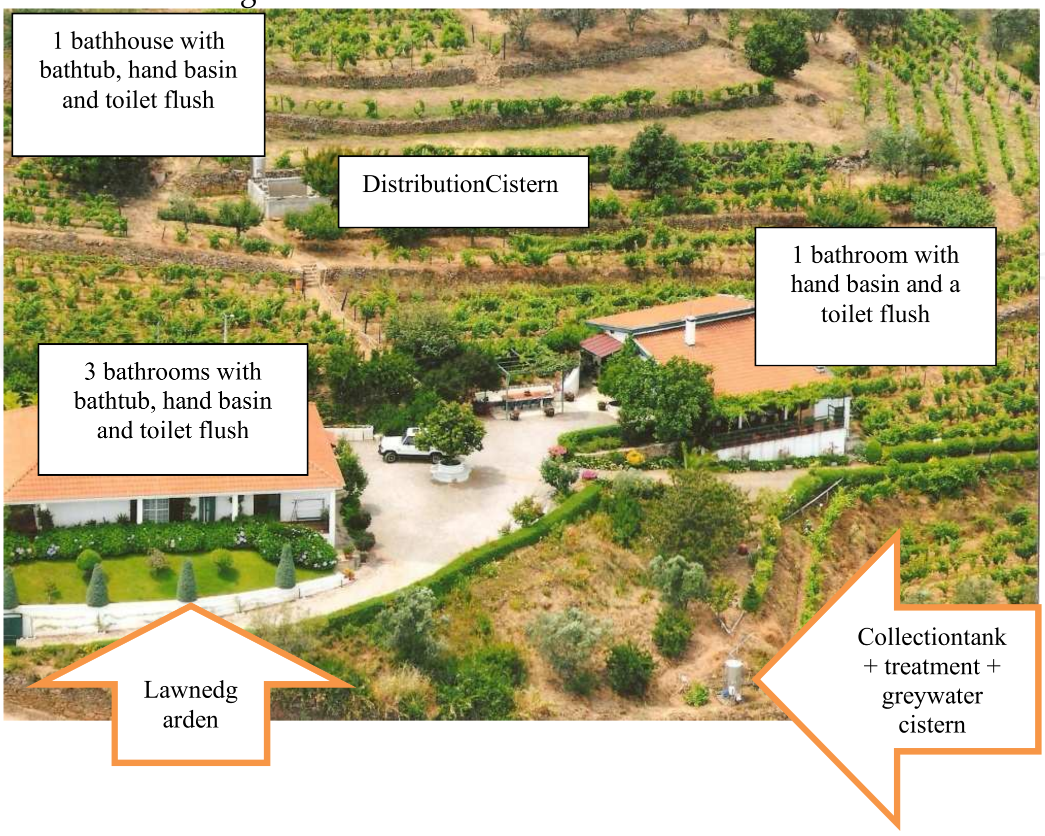


Fig. 4. Quinta da Casa Nova.

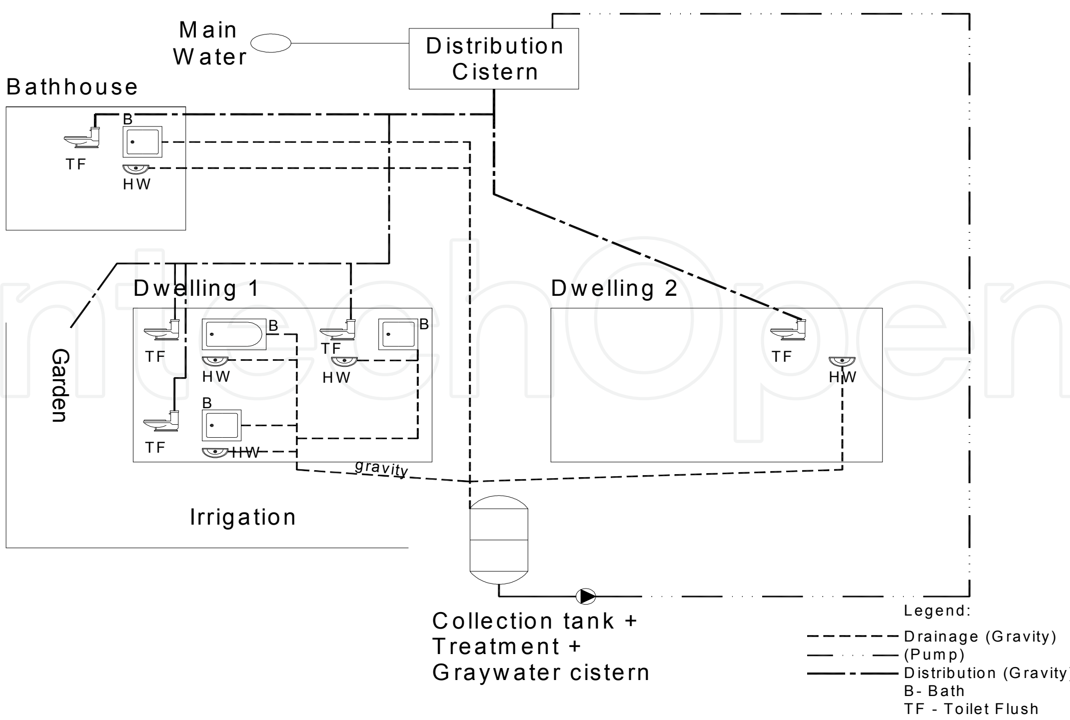


Fig. 5. Greywater system.

Additionally, to characterize light greywater produced in the dwelling it was disconnected from the system described above the drainage of water from the kitchen and laundry. Thus, were drained into the tank previously described only the greywater from the tub, sink and bidet. There have been two sampling campaigns (one in February of 2007 and other in March of 2008) to characterize the TGW and one for the characterization of the LGW (In March of 2008). Also, the potable water physico-chemical characterization was evaluated.

The parameters analysed (Tables 9 and 10) were chosen based on the existing law for irrigation water quality. Given the huge analysis costs, the second campaign was less inclusive, repeating only the most relevant parameters.

In each campaign, it was collected a 5.5 L of greywater sample which was well preserved and sent to a laboratory for the analysis of these parameters. In addition to the above parameters were measured some parameters *in situ* with sensors, such as pH, redox potential, dissolved oxygen and the electrical conductivity. For measuring pH, redox potentialand the electrical conductivity it were used two multisensorial probes, namely a FU20 pH/redox sensor and a ISC40 inductive conductivity sensor, both from YOKOGAWA. To measure dissolved oxygen it was used DO402G-E/U and FD30V27-00-FN/CO5/S50 dissolved oxygen sensor and analyser from YOKOGAWA. This last parameter was only measured for the LGW. The readings of electrical conductivity (Ce) were converted in total dissolved solids (TDS) using the following expression (APHA, 1992):

$$Ce(dS/m) \times 640 = TDS(mg/l) \tag{1}$$

The knowledge of the electrical conductivity and TDS allows the evaluation of the water salinity, an important parameter for irrigation reuse.

Knowing sodium, calcium and magnesium content in mg/l (Na^+, Ca^{2+}, Mg^{2+}) it was possible to calculate the sodium absorption reason (SAR):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{2}$$

3.2.1.2 Greywater quality per domestic device

In order to characterize 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 physico-chemical parameters were analysed (*cf. 4.2.1.1.* for probes): pH, electric conductivity, TDS, temperature and COD. All of them, except COD, were analysed with sensors. In respect to microbiological parameters it was determined the total and faecal coliform content in the laboratory, by the membrane filter technique, a highly reproducible method, using standardised selective and solid media (APHA, 1992).

3.2.1.3 Quantitative characterization of greywater produced by

To determine the amount of greywater produced by each domestic device it was performed two sampling campaigns, (7 and 21 days in July of 2008) in 3 different houses, located in Vila Real, Trás-os-Montes and Alto Douro in northern Portugal. During the two campaigns it was observed the volume consumed by each usage, on the counter.

3.2.1.4 Needs for irrigation

To make the quantitative characterization of water demand it was estimated the amount spent in irrigation. To estimate the amount of water spent on irrigation it was conducted a door to door survey in 12 houses with gardens in a residential area of Vila Real, which recorded the number of times per month or per day that there was irrigation and its duration. The consumption data was calculated using the weighted average water consumption of each resident.

3.3 Results and discussion

3.3.1 Greywater characterization: Quality and quantity

3.3.1.1 Total greywater and light greywater quality

The values of the parameters analysed in the TGW, LGW and drinking water are presented in Table 6. In these tables are presented the national legal / regulatory criteria related to water quality for irrigation. Additionally, it presents a range of values, or the average value, depending on the cases, taken from the bibliography. Some of the bibliographic values are presented for greywater from various sources (e.g. kitchen or bathroom) and not necessarily to the mixture of all the greywater.

The most remarkable mark of these waters is the great qualitative variability, which persists even with a high number of repetitions (Friedler & Butler, 1996). In the present study and in agreement with other precedents there were very different values for most parameters, especially with regard to mean concentrations of dissolved oxygen, total coliforms and faecal coliforms.

Given the large range of values indicated in the bibliography, the concentration of most analysed parameters falls within the range of values found by other researchers. It should be noted for the TGW the case of chlorides, and faecal coliform. There were analysed the chlorides while in the bibliography it is presented the total chlorine, which appears with higher concentration values. The value of BOD_5 found is lower than those found in the literature, which is indicative of a lower concentration of organic matter in this sample. For faecal coliform, the value found is higher than the values referenced in the bibliography which could indicate faecal contamination. It is worth noting refer that, in spite of total and faecal coliforms are widely used as indicators of faecal pollution, high levels of them could not necessary indicate pathogen presence (Birks & Hills, 2007), as well their absence does not means that water is pathogen free (Gerba& Rose, 2003). Because some bacterial enteric groups can survive and growth within water closets and pipes (Barker & Bloomfield, 2000), there had been the need to search for more reliable indicators (Scott et al., 2002; Ottosona & Stenström, 2003; Cimenti et al., 2007; Griffin et al., 2008).

With respect to LGW, the parameters values analysed are in the range of values referenced in the bibliography, with the exception of faecal coliform which showed higher values in this campaign and the conductivity that was lower (294 mS/cm) to that presented by Eriksson et al. (2009) (> 700 mS/cm). However, these researchers related this value with the

		TGW			National regulation			
Parameters	Drinking water	First	Second	LGW	RMV	AMV	EPA (2004)	Other References*
Al (mg/L)	0.06	5.8	5.1	1.1	5.0	20.0	-	-
As (mg/L)	<0.01	0.01	-	0.01	0.1	10.0	-	-
Ba (mg/L)	-	0.02	0.02	0.02	1.0	10.0	-	-
B (mg/L)	-	0.2	-	0.2	0.3	-	-	0 - 3.8
Cd (mg/L)	<0.001	0.07	-	0.02	0.01	0.05	-	-
Ca (mg/L)	4.8	9.0	12.0	8.0	-	-	-	-
Pb (mg/L)	<0.005	0.1	-	0.1	5.0	20.0	-	-
Cl^- (mg/L)	17.8	72.0	83.0	51.0	70.0	-	-	10.0 (1)
Cu (mg/L)	0.07	0.16	-	0.4	0.2	-	-	-
Cr (mg/L)	<0.002	0.1	-	0.1	0.1	20.0	-	-
Fe (mg/L)	0.02	0.48	0.63	0.93	5.0	-	-	-
Mg (mg/L)	4.8	6.0	7.0	5.0	-	-	-	-
Mn (mg/L)	0.02	0.1	0.1	0.1	0.1	10.0	-	-
Ni (mg/L)	<0.006	0.1	-	0.1	0.5	2.0	-	-
NO_3^- (mg/L)	-	2.0	4.0	2.0	50.0	-	-	0.05 – 74 (2)
Phosphorus(mg/L)	-	8.0	-	2.0	-	-	-	0.1 – 170 (3)
Se (mg/L)	-	0.05	-	0.05	0.02	0.05	-	-
Na (mg/L)	14.8	200.0	170.0	48.0	-	-	-	7.4 - 641
SO_4^{2-} (mg/L)	27.3	130.0	-	14.0	575.0	-	-	-
Zn (mg/L)	-	0.11	0.10	0.22	2.0	10.0	-	0.09 - 6.3
TSS (mg/L)	0.0	51.0	85.0	15.0	60.0	-	-	40 - 120
TDS (mg/L)	46.0	-	-	188.2	640.0	-	-	-
COD (mg/L)	-	720.0	770.0	270.0	150.0	-	-	8000.0
BOD_5 (mg/L)	-	170.0	310.0	140.0	40.0	-	≤10	90 - 360
TOC (mg/L)	-	160.0	250.0	1100.0		-	-	30 - 880
Total coliform (CFU/100 mL)	n.d.	1.3×10^8	4.8×10^7	4.9×10^6		-	-	$70 - 4 \times 10^7$
Faecal coliform (CFU/100 mL)	n.d.	4.3×10^4	3.7×10^3	8.2×10^4	1.0×10^2	-	n.d.	$1 - 9 \times 10^4$
Helminths eggs (n/L)	-	0	0	0		-	-	-
Salmonella (CFU/100 mL)	-	0	0	0	1	-	-	-
SAR	-	13.0	51.0	18.8	8.0	-	-	-
pH	6.8	8.9	7.1	6.9	6.5 - 8.4	4.5 - 9.0	6.0 - 9.0	6.4 - 10
Dissolved O_2 (mg/L)	-	7.8	1.3	1.9	-	-	-	2.2 – 5.8
Temperature (ºC)	-	20.0	11.0	16.5	-	-	-	-
Potential Redox (mV)	517.7	-	204.6	164.0	-	-	-	-
Conductivity (μS/cm)	168.0	-	-	294.0	1000.0	-	-	82 - 1565

Table 6. Mean values of the parameters analysed in drinking water, total greywater (TGW) in the first and second campaign, and light greywater (LGW). (1)Total Cl; (2)Total Nitrogen; (3)phosphate; n.d. – Not detectable; Recommended maximum value (RMV) and Admissible maximum value (AMV). * Siegrist et al., (1976); Christova-Boal et al., (1996); Burrows et al., (1991); Rose et al., (1991); Shin et al., (1998); Almeida, et al., (1999); NUEA (2001); Friedler (2004).

high conductivity presented in drinking water from Copenhagen. The same authors argued that the increase of the electrical conductivity is accompanied by an increase in COD, that might indicate the presence of cations as sodium, used in soaps and anions (chloride) used in other types of products such as disinfectants. Also in this work the drinking water conductivity showed a considerable value.

In the second campaign, the amount of dissolved oxygen has been substantially lower than the one of the first campaign, a result consistent with the values obtained for COD and BOD_5, which is higher in this campaign. In fact, the dissolved oxygen decreases or disappears when the water gets large amounts of biodegradable organic substances, since most of the microorganisms responsible for its degradation are aerobic.

As shown by the results presented, LGW still contain large amounts of organic matter and are heavily contaminated (values greater than 104 CFU/100 mL).

Analysing the results from the legal point of view of water reuse for irrigation, it could be argued that the concentration of most parameters in the TGW is not an obstacle. Unlike the aluminium concentration, total suspended solids and chlorides, all above the VMR, and the concentration of cadmium which is above the VMA, limiting the direct use of effluent for this purpose. It should be noted that the value of chlorides of drinking water also was substantial.

Also in the LGW, most of the parameters show concentration values that do not limit their application in irrigation. There are, however, some whose concentrations are an obstacle to this application as is the case of faecal coliform, cadmium and copper, whose values are presented above the VMR and selenium with value equal to the VMA. RAS, in this case shows values above the VMR of water for irrigation, thus indicative of a high salinity.

With regard to the microbiological parameters, total and faecal coliforms, LGW were highly contaminated. Consequently, it could not be directly used for irrigation. Considerably decreasing of microbial load could be achieved with sand filtration and coagulation, combined with chorine and UV disinfection (Tajima et al., 2007; Friedler et al., 2008; Friedler & Gilboa, 2010).

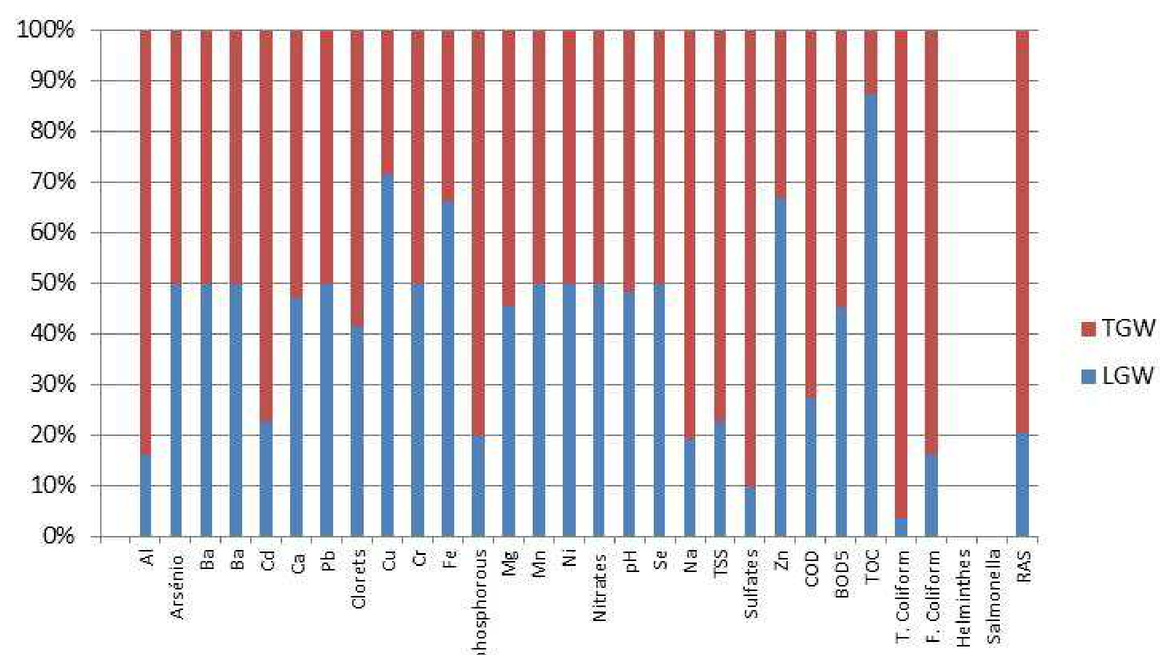


Fig. 6. Relative concentrations of each parameter in Total Greywater (TGW) and Light Greywater (LGW).

In general and as it would be expected, the concentration of the parameters analysed in the TGW is superior to the LGW (Fig. 6). There are, however, some exceptions such as copper (Cu), iron (Fe), zinc Zn) and total organic carbon (TOC), where the concentration is greater in the LGW. For the microbiological parameters, aluminium, cadmium, phosphorus and sodium, TSS, sulphates, COD and RAS concentration difference between the LGW and TGW is evident, and is significantly higher in TGW.
The concentrations values of the parameters is highly variable depending on several factors: since the type of use to the type of detergent used, however, it is most evident pollutant and contaminant load in TGW than in LGW, in particular at the microbiological level, and, in principle, it is easier to treat LGW in order to obtain an effluent for reuse. This finding is in agreement with other referenced work (Almeida et al., 1999; Butler, 1991; Butler et al., 1995)

3.3.1.2 Greywater quality per domestic device

As said before, samples from raw greywater were analysed for pH, conductivity, TDS and COD. In Table 7 there are presented the mean values of each parameter (n=8) by appliance, as well as its standard deviation.
To investigate the concentration of bacteria in raw greywater we enumerated total and faecal coliforms (Table 8).

Source	pH	COD (mgO2/L)	Conductivity (μS/cm)	TDS (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	96.6 ±42.3	60.6
Drinking water	6.7 ± 0.8	-	71.9 ± 73.5	46.0

Table 7. Pollutant concentration per domestic device. COD- Chemical Oxygen Demand; TDS Total Dissolved Solids.

Source	Total coliforms	Faecal coliforms
Wash-basin	$5.4 \times 10^4 \pm 3.5 \times 10^2$	$3.3 \times 10^4 \pm 5.6 \times 10^2$
Bath/shower	$2.2 \times 10^5 \pm 1.1 \times 10^5$	$4.5 \times 10^4 \pm 6.0 \times 10^4$
Bidet	$1.7 \times 10^5 \pm 6.1 \times 10^4$	$2.1 \times 10^2 \pm 3.9 \times 10^2$
Kitchen sink	$6.7 \times 10^6 \pm 3.3 \times 10^5$	$7.0 \times 10^3 \pm 8.9 \times 10^3$
Dishwasher	$2.8 \times 10^6 \pm 2.6 \times 10^5$	$1.5 \times 10^5 \pm 1.7 \times 10^5$
Washing machine	$5.7 \times 10^4 \pm 4.0 \times 10^4$	n.d.
Blended samples	$1.0 \times 10^7 \pm 2.7 \times 10^6$	$2.0 \times 10^5 \pm 6.0 \times 10^4$

Table 8. Total and faecal coliform concentration (CFU/100 mL) for each domestic device (mean of 8 independent samples, with 3 replicas ± standard deviation).n.d. – no detection.

Comparing the mean values of pH recorded for drinking water of different houses with greywater from different sources, it appears that, except for the greywater came from the tub and sink, this value is higher in greywater.

The higher pH values recorded for the water from the washing machines and dishwashers is possibly due to the type of detergents used in the washing. The standard deviation does not assume, in this case, very relevant values. Washing machines and dishwashers reveal again the highest values with respect to conductivity. In fact, the water from the dishwasher has values 20 times higher than the drinking water and water from the washing machine, 50 times higher. The remaining values are close to those recorded for drinking water. The results for this parameter lead to very high SDT values especially in these two domestic devices. It should be noted the high value of standard deviation associated with these results.
The COD values are high, with the exception of water from the bidet, reaching a maximum of 1781.5 mg/L in the sink. Most of the COD derived from the chemicals used and is therefore higher in the laundry and kitchen, with great variations from house to house.
Analysing the results obtained with the purpose of water re-use for irrigation, it could be said that:

- Water for irrigation, requires its improvement and so the separation of sources, distinguishing those which contains a high pH (MLL and MLR). Excluding these waters it is produced a clear greywater with a pH in the range of 6,5-8,4, with features for use in irrigation, under the law (NP 4434, 2005).
- The values of conductivity and TDS present in the MLL and MLR render the direct reuse of water for irrigation, under Decree-Law 236/98, which refers to maximum recommended 1000 mS/cm;
- With regard to microbiological parameters, it make impossible their direct reuse of effluent in irrigation.

Microbiological contamination of total and faecal coliforms is always very significant, with the exception of washing machine that did not presented any faecal coliforms, whatever the dilution used.
Analysing Fig.7 it can be seen that the domestic devices from kitchen and laundry, are the main pollutant concentration producers, although the bath also contained significant amounts of faecal coliform. In fact, the greywater from the kitchen may contain numerous microorganisms from the food washing and is usually the most polluted source.

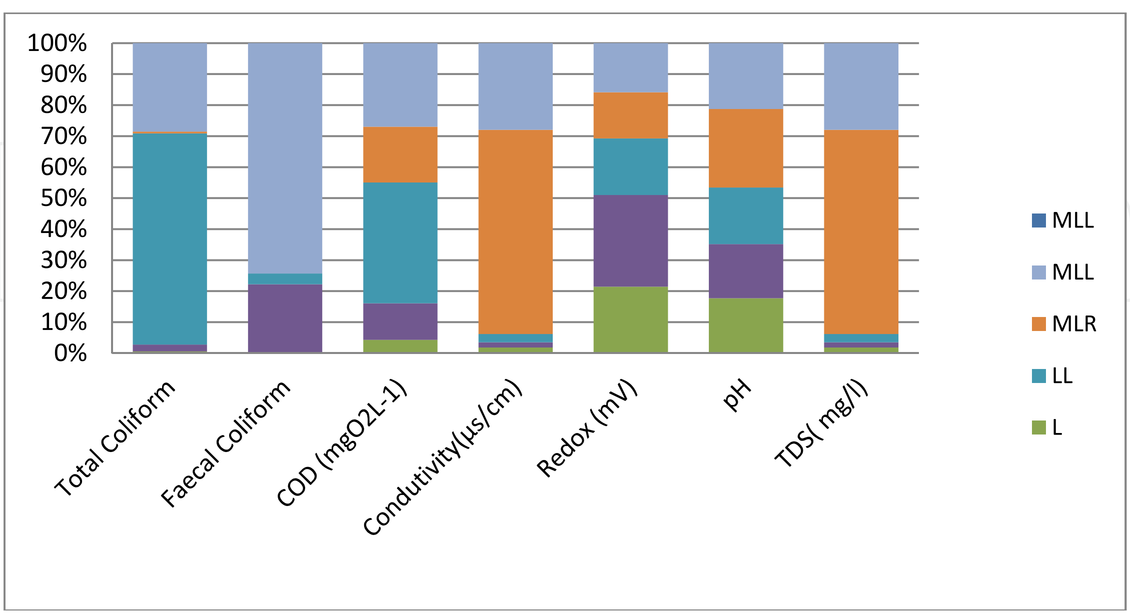


Fig. 7. Relative concentrations of each parameter in each domestic device. MLL- Dish Washer; MLR- Washing machine; LL- Kitchen sink; BA- Bathtub; L- Washbasin;

3.3.1.3 Quantitative characterization of greywater produced by domestic device

In Fig. 8the percentage of water generated by each domestic device is represented.
The capitation found for all sanitary appliances was 114.7 L/person.day, corresponding 95.7 L/person.day to total greywater and 48.6 L/person.day to light greywater.
The study results indicate the great variability associated with the use of some of the sanitary appliances studied, including the MLR, the MLL, the bathtub and the kitchen sink. The high deviations from the average readings for the MLL and MLR are related on the one hand to the fact that the machines were not connected every day and so there were many days of zero consumption. On the other hand, it is related to the type of program used. It should be noted that the sample on the washing machines is not representative, since only one house was equipped with these device. With respect to the tub, the large deviation result on the different habits of the consumers, including the bath duration and the use of water during the same (close or not the tap during soaping).The kitchen sink has a high value of standard deviation, due possibly to the lifestyle of consumers. The fact that consumer's lunch and dinner away can lead to significant deviations from the average. As it has been demonstrated is the bath that is associated with higher value of capitation, followed by the kitchen sink and toilet flushing. The wash basin and the machines occupy a lower share of consumption. These results differ somewhat from those reported in PNUEA, since the latter is associated with 41% of total consumption to flush, followed by 39% to baths and showers. However, the percentage of baths and showers provided by PNUEA,(2005) comes into consideration with the intake valves in the general, without specifying what their origin, and may include a sink and bidet. In this study, washing machines also occupy the lowest-ranking of consumption. Table 9 shows the range of values (maximum and minimum) referenced by Friedler, (2004) concerning the diverse bibliography compiled by this researcher.

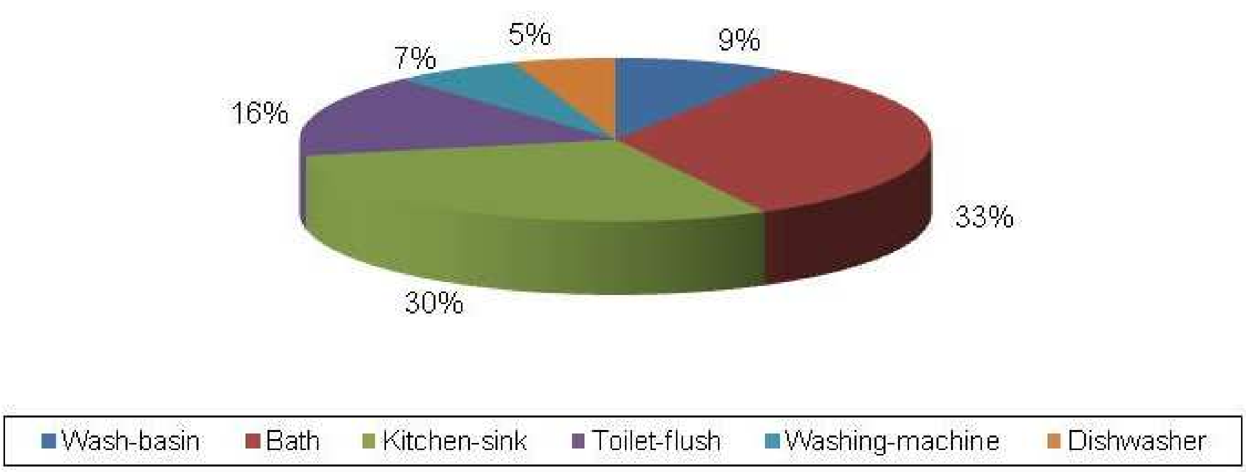


Fig. 8. Percentage of water generated by each domestic device.

Table 9 also shows the limits proposed by the NSW (2006), which can serve as comparison. On this basis we can see that the realities vary greatly. The value of total greywater *per capita* found in this study falls within the range of values that appears in the bibliography.
After made a brief analysis on how much greywater could be expected, it will be interesting knowing if the volume produced is sufficient to meet the demand for *in situ* reuse.

Moreover, knowing the needs, it will be possible to know if it can be reused only the type of greywater less polluted.

Domestic device	Values range	Values mean (n=6)	Friedler (2004)	NSW (2006)
Bath	27.8 – 48.2	38.2	12 - 20	193
Wash basin	7.1 – 12.9	10.4	8 - 15	28
Kitchen sink	17.4 – 50.6	34.0	13 - 25	44
Dishwasher	1.3 – 10.7	6.1	2 - 6	
Washing machine	5.1 – 19.1	7.5	13 - 60	135
Total mixture	48.5 – 141.5	96.2	48 - 126	400

Table 9. Capitation values (L/person.day) found in this study and its comparison with others found in similar studies, in other countries.

3.3.1.4 Needs for irrigation

The maintenance of garden areas and lawns requires a significant amount of water, depending, however, on its geographic location and season. In summer, for example, this volume may represent 60% of the total consumption of a dwelling. Analysing in detail the domestic component can be considered that watering is done only in the 6 months of low rainfall (April to September). In this study it was concluded that the need for irrigation in those months, would be 6794 L/house.month to a garden area of 20 m^2, implying 226,5 L/house.day (11,5mm/day), one volume, again, easily replaced by greywater, though storage is needed in the months of lower demand. Investigations revealed an average frequency of use in 30 irrigations per month with a duration average of 11.5 minutes per irrigation. According to the PNUEA in the 5 months of lowest rainfall the averages needs of water in a garden located in Portugal are 200 mm/month. According to data from INE (1999), 64% of Portuguese homes are houses, of which 30% have outdoor space and garden or lawn with an average of 40 m^2/house. Thus, the average consumption per garden will be 40 m^3 per year. According to this plan, in these months, irrigation consumes 266.7 L/house.day (6,7 mm/day), a value lower than the one found in this paper. In Israel, Friedler (2004) states that the reuse of greywater for gardens would need 8-10 L/person.day, or 24,8-30 L/house.day taking in account the average size of the cluster for Portugal. Here it is shown the variability resulting from geographical location and availability of water resources.

Table 10 depicts the amounts of greywater generated by type (supply) and demand for non-potable uses considered.

	Source/use	Volume (L/house/day)
Greywater	TGW	296.7
	LGW	150.7
	Bath	118.4
	Wash basin	31.2
Demand	Irrigation	226.5

Table 10. Amounts of greywater generated by supply type, and demand for non-potable uses.

In conclusion, depending on the type of housing and green areas, the provision of greywater is more than enough to supply the water consumption in toilets, car-washing and to supplement irrigation.

3.4 Conclusions and future recommendations

The results showed that in a reuse perspective it would be best to separate the greywater from the kitchen and laundry of the other sources in order to obtain a clear greywater that would in itself have a better quality. In any case it would have an exempt treatment, even simplified.

Depending on the type of housing and the amount of landscaped green areas, the provision of greywater is enough to supplement the water consumption in irrigation.

There are several possibilities for reuse, which can be considered in order to take full advantage of greywater. The greywater generated in a dwelling, may not be necessary as a whole. Taking into account that the supply is exceeding demand and that the quality of greywater generated can be improved taking into account the separation of sources, it can be assumed the reuse of only part of this water, that is, the one that has the best quality.

4. References

Al-Jayyousi, O.R. (2003). Greywater reuse: towards sustainable water management. *Desalination*, 156, pp: 181-192

Almeida, M.C., Butler, D. & Friedler, E. (1999). At-source domestic wastewater quality. *Urban Water*, 1, pp: 49-55

APHA (1992). Standard Methods for the Examination of Water and Wastewater 18th ed. American Public Health Association, Washington DC In: Greenberg, A.E., Clesceri, L.S., Eaton, A.D.(Eds.)

Barker J.& Bloomfield S. (2000).Survival of *Salmonella* in bathrooms and toilets in domestic homes following salmonellosis. *Journal of Applied Microbiology*, 89, pp: 13-44

Birks, R. & Hills, S. (2007). Characterization of indicator organisms and pathogens in domestic greywater for recycling.*Environmental Monitoring and Assessment*, 129, pp: 61-69

Burrows, W. D., Schmidt M. O.,Carnevale R. M. &Shaub, S. A. (1991). Nonpotable reuse: development of health criteria and technologies for shower water recycle. *Water Science Technology*, 24(9), pp: 81-88

Butler, D., Friedler E. &Gatt K. (1995). Characterizing the quantity and quality of domestic wastewater.*Water Science and Technology*, 31(7), pp: 13-24

Butler, D. (1991). A small-scale study of wastewater discharges from domestic appliances. *Journal of Institution of Water and Environmental Management*, 5 (2), pp. 178–185

Chen, Y., Lerner, O., Shani, U. & Tarchitzky, J. (2003).Hydraulic conductivity and soil hydrophobicity: effect of irrigation with reclaimed wastewater. In: Lundstrum U, editor. Nordic IHSS Symp Abundance and function of natural organic matter species in soil and water, 9th. Sweden: Sundsvall; 2003

Christova-Boal, D., Eden, R.E. & McFarlane, S. (1996). An investigation into greywater reuse for urban residential properties.*Desalination*, 106, pp: 391-397

Cimenti, M, Hubberstey, A., Bewtra, J.K. & Biswas, N. (2007).Alternative methods in tracking sources of microbial contamination in waters.*Water SA*, 33 (2), pp: 183-194

Cogan, T.A., Bloomfield, S.F. & Humphrey, T.J. (1999).The effectiveness of hygiene procedures for prevention of cross contamination from chicken carcasses in the domestic kitchen.*Letters in Applied Microbiology*, 29, pp: 354-358

Decreto-Lei nº236/98 de 1 de Agosto (1998).

Dixon, A.M., Butler, D. & Fewkes, A. (1999). Guidelines for greywater reuse: Health issues. *Journal of the Institution of Water and Environmental Management*, 13, pp: 322-326

EPA (2004).Guidelines for Water Reuse. U.S. Environmental Protection Agency. Washington DC.

Eriksson, E. & Donner, E. (2009). Metals in greywater: sources, presence and removal efficiencies. *Desalination*, 248 (1-3), pp: 271-278

Eriksson, E., Andersen, H.R., Madsen, T.S. & Ledin A. (2009).Greywater pollution variability and loadings.*Ecological Engineering*, 35 (Issue 5), pp: 661-669

Eriksson, E., Auffarth, K., Henze, M. &Ledin A. (2002). Characteristics of grey wastewater.*UrbanWater*, 4 (1), pp: 85-104.

European Comission (2006). Proposal for a Directive of the European Parliament and of the Council on Environmental Quality Standards in the Field of Water Quality Policy and Amending Directive 2000/60/EC, 2006.

Friedler, E., Kovalio, R. & Gail, N.I. (2005). On-site greywater treatment and reuse in multi-storey buildings. *Water science and Technology*, 51(10), pp: 187-194

Friedler, E. & Butler, D. (1996).Quantifying the inherent uncertainty in the quantity and quality of domestic wastewater.*Water Science and Technology*, 33(2), pp: 65-78

Friedler, E. (2004). Quality of individual domestic greywater streams and its implication on on-site treatment and reuse possibilities.*Environmental technology*, 25(9), pp: 997-1008

Friedler, E. & Gilboa, Y. (2010).Performance of UV disinfection and the microbial quality of greywater effluent along a reuse system for toilet flushing.*Science of the Total Environment*, 408, pp: 2109-2117

Friedler, E., Katz, I. &Dosoretz, C.G. (2008).Chlorination and coagulation as pretreatments for greywater desalination.*Desalination*, 222: pp. 38–49

Garland, J.L., Levine, L.H., Yorio, N.C., Adams, J.L. & Cool, K.L. (2000). Greywater processing in recirculation hydroponic systems: phytotoxicity, surfactant degradation and bacterial dynamics. *Water Research*, 34, pp: 3075-3086

Gerba, C.P. & Rose, J.B. (2003). The indicator concept in wastewater reclamation: past, present and future. 4th International Symposium on Wastewayer Reclamation and Reuse, Mexico City.

Gray, S.R. & Becker, N.S.C. (2002). Contaminant flows in urban residential water systems. *Urban Water*, 4 (4), pp: 331-346

Griffin, J.S., Plummer, J.D. & Long, S.C. (2008). Torque teno virus: an improved indicator for viral pathogens in drinking waters.*Virology Journal*, 5: 112 doi:10.1186/1743-422X-5-112

Grisham, A., & Fleming, W.M. (1989).Long-term Options for Municipal Water Conservation. *Journal of the American Water Works Association,* 81 (3), pp: 34-42

Gross, A., Azulai, N., Oron, G., Ronen, Z., Arnold, M. & Nejidat, A. (2005). Environmental impact and health risks associated with greywater irrigation: a case study. *Water Science and Technology*, 52 (8), pp: 161-169

Gross, A., Kaplan, D. & Baker, K. (2007). Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB). *Ecological Engineering*, 31, pp: 107-114

Günther, F. (2000). Wastewater treatment by greywater separation: Outline for a biologically based greywater purification plant in Sweden. *Ecological Engineering*, 15, pp: 139-146

Hargelius, K., Holmstrand, O. & Karlsson, L. (1995). Hushållsspillvatten Framtagandeavnyaschablonvärdenför BDT-vatten. In Environmental Protection Agency EPA (Ed.), Vadinnehålleravloppfrånhushåll? Näringochmetaller i urinochfekaliersamt i disk-, tvätt-, bad- &duschvatten Stockholm: Swedish EPA (Naturvårdsverket).

Jackson, R. &Ord, E. (2000). Greywater re-use – Benefit or liability? The UK perspective. *Water*, 21: pp: 38-39

Jeppesen, B. (1996). Domestic Greywater reuse: Australian challenge for the future. *Desalination*, 106 (1-3), pp: 311-315

Jury, W.A., Vaux Jr., H.J. (2007). The emerging global water crisis: managing scarcity and conflict between water users. *Advances in Agronomy*, 95, pp: 1-76

Laak, (1974). Relative pollution strengths of undiluted waste materials discharged in households and the dilution waters used for each Manual of grey water treatment practice (pp. 68-78). Michigan, USA: AnnArbor.

Manville, D.,Kleintop, E., Miller, B., Davis, E., Mathewson, J. & Downs, T. (2001). Significance of indicator bacteria in a regionalized wastewater treatment plant and receiving waters. *International Journal of Environment and Pollution*; 15 (4), pp: 461-466

Marecos do Monte, M.H.F. (2008). Sustainable Water Reuse in Portugal. *WSEAS Transactions of Environment and development*, 4 (9), pp: 716-725

Marecos do Monte, M.H.F. (2008b). Portugal implements sustainable water reuse. *Proceedings of 4th IASME/WSEAS International Conference on ENERGY, ENVIRONMENT, ECOSYSTEMS and SUSTAINABLE DEVELOPMENT (EEESD'08)*, pp. 478-483. ISBN 978 960 6766 71 8, Algarve, Portugal, June 11-13, 2008

Matos, C. (2009). Reutilização de água: Utilização de águas cinzentas *insitu*. PhD. Thesis. Universidade de Trás-os-Montes e Alto Douro. Pp: 167.

Matos, C., Sampaio, A. & Bentes, I. (2010). Possibilities of greywater reuse in non-potable in situ urban applications, according with its quality and quantity. *WSEAS Transactions on Environment and Development* 7 (6), pp: 499-508

Mekorot. Wastewater Treatment and Reclamation.*Watec 2007*, TelAviv , Israel ; 2007

Melo-Batista, J. (2002). A melhoria da eficiência do uso eficiente da água como contributo para a sustentabilidade dos recursos naturais 10 Encontro Nacional de Saneamento Básico: Uso sustentável da água: situação portuguesa e perspectivas de futuro.

Misra, R.K., Patel, J.H. &Baxi, V.R. (2010). Reuse potential of laundry greywater for irrigation based on growth, water and nutrient use in tomato. *Journal of Hydrology*, 2010, 386 (1-4), pp: 95-102

Misra, R.K. &Sivongxay, A. (2009). Reuse of laundry greywater as affected by its interaction with saturated soil. *Journal of Hydrology*, 366, pp: 55-61

Moura, B., Dionísio, L., Beltrão, J. & Borrego, J.J. (2006). Reclaimed wastewater for golf course irrigation.*WSEAS Transactions on Environment and Development* 2 (5), pp: 652-658

Neal, J. (1996). Waste water reuse studies and trial in Canberra. *Desalination*, 106, pp: 399-405

Nolde, E. (1999). Greywater reuse system for toilet flushing in multi-storey buildings- over ten years experience in Berlin. *Urban water*, 1, pp: 275-284

Nolde, E. &Dott, W. (1991).Verhalten von hygienischbakterien und Grauwasser- Einfluss der UV-Desinfektion and Wiederverkeimung.*GwfWasserAbwasser*, 132 (3), pp: 108-114

Norma Portuguesa 4434- Reutilização de águas residuais urbanas tratadas para rega (2005).

NSW (2006).Guideline for sewered Residential Premises (Single households) Greywater Reuse.

Ottosona, J. &Stenström, T.A. (2003).Faecal contamination of greywater and associated microbial risks.*Water Research*, 37, pp: 645–655

PNUEA (2001). Programa Nacional para o Uso Eficiente da Água. MAOT-IA Lisboa.

Rose, J. B., Sun, G-S., Gerba, C.P. & Sinclair, N.A. (1991). Microbial quality and persistence of enteric pathogens in graywater from various households sources. *Water Research*, 25 (1), pp: 37-42

Scott, T.M., Rose, J.B., Jenkins, T.M., Farrah, S.R. & Lukasik, J. (2002). Microbial Source Tracking: Current Methodology and Future Directions. *Applied and Environmental Microbiology*, 68 (12): 5796–5803

Shin, H.-S., Lee, S.-M., Seo, I.-S., Kim, G.-O., Lim, K.-H.& Song, J.-S. (1998). Pilot scale SBR and MF operation for the removal of organic and nitrogen compounds from greywater. *Water Science Technology*, 38 (6), pp. 79-88

Siegrist, H., Witt M. & Boyle, W.C. (1976).Characteristics of rural household wastewater. *Journal of the Environmental Engineering Division*, 102(EE3), pp: 533-548

Stenström, T. (1985). Infiltration i mark. (Infiltration into soil). Swedish EPA, snv pm 3051.

Surendran, S., Wheatley, A. D. (1998).Grey-water reclamation for non potable reuse.*Journal of the Chartered Institution of Water and Environmental Management*, 6, pp: 406-413

Tarchitzky J., Lerner, O., Shani, U., Arye, G., Lowengart-Aycicegi, A., Brener, A. & Chen, Y. (2007). Water distribution pattern in treated wastewater irrigated soils: hydrophobicity effect. *European Journal of Soil Science,* 58 (3), pp: 573-588

Tchobanoglous, G., Burton, F.L. &Stensel, H.D. (2003).*Wastewater Engineering: treatment and reuse*. New York: Mcraw-Hill, 1819 pp.

Travis, M.J., Weisbrod, N. & Gross, A. (2008). Accumulation of oil and grease in soils irrigated with greywater and their potencial role in soil water repellency.*Science of the Total Environment*, 394 (1), pp: 68-74

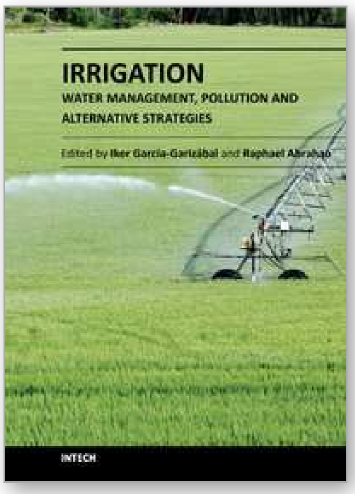
Travis, M.J., Wiel-Shafran, A., Weisbrod, N., Adar, E. & Goss, A. (2010).Greywater reuse for irrigation: effect on soil properties. *Science of the Total Environment*, 408 (12), pp: 2501-2508

Wallach, R., Ben-Arie, O. & Graber, E.R. (2005).Soil water repellency induced by long-term irrigation with treated sewage effluent. *Journal of Environmental Quality*, 34 (5), pp: 1910-1920

WHO.(1989). Health guidelines for the use of wastewater in agriculture and aquaculture. WHO, 1989, Technical Report Series, No. 776.

WHO.(2006). Guidelines for the Safe Use of wastewater, excreta and Greywater. Volume I: Policy and Regulatory Aspects. WHO, UNEP, 2006.

Wiel-Shafran, A., Ronen, Z., Weisbrod, N., Adar, E. & Gross, A. (2006). Potential changes in soil properties following irrigation with surfactant-rich greywater. *Ecological Engineering*, 26 (4), pp: 348-354



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Irrigated agriculture is the most significant user of fresh water in the world and, due to the large area occupied, is one of the major pollution sources for the water resources. This book comprises 12 chapters that cover different issues and problematics of irrigated agriculture: from water use in different irrigated systems to pollution generated by irrigated agriculture. Moreover, the book also includes chapters that deal with new possibilities of improving irrigation techniques through the reuse of drainage water and wastewater, helping to reduce freshwater extractions. A wide range of issues is herein presented, related to the evaluation of irrigated agriculture impacts and management practices to reduce these impacts on the environment.

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