TREATMENT OF DOMESTIC GREYWATER THROUGH GREEN WALLS

Summary of dissertation for the degree of Master in Environmental Engineering

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ABSTRACT

The purpose of the present article is to test the feasibility of a grey water treatment system (Green walls) at a laboratory scale. Treatments of this type have been developed driven by the aggravation of the lack of water and by the need for new sources of this resource with accessible and efficient treatments.

In addition to the reuse and water use, the associated benefits include the valorization of space and the introduction of more green spaces in urban centers, which in turn lead to other benefits such as CO_2 reduction, O_2 production, development of healthier microclimates and improvement of aesthetics.

It was thus intended to analyze a list of variables that contribute to the results of this type of treatment, such as the characteristics of grey waters, the influence of the filling medium (cork and a porous ceramic), plant species, hydraulic loads and pollutant removal performance. This solution seems to be quite attractive, due to its economic benefits and feasibility in the treatment.

Keywords – Green Walls, Greywater, Sustainability, Wastewater Management, Pollutant Removal.

1. INTRODUCTION

1.1. Problem

When verifying that water scarcity is a real problem, technologies have been developed to allow the correct use and treatment of this resource. The current challenge requires the development of low-cost, low-maintenance technologies that are at the same time highly efficient in wastewater treatment.

One of the alternatives that has been found viable is the prior separation of greywater from the raw sewage, since it has a lower level of pollutants. This is defined by urban wastewater which includes discharges from baths, showers, lavatories (bathroom and kitchen) and washing machines but do not contain wastewater from toilets (Li et al., 2009). The water from the kitchen sink is not consensual in the description given above as it may contain food waste, oils and fats that contribute to the increase of the organic load and the consequent formation of bad smells.

However, this alternative allows obtaining water with excellent characteristics to be used, for example, in the irrigation, yet does not present quality compatible with a direct reuse, thus requiring treatment. Greywater accounts for about 50-80% of the total domestic wastewater volume (Li et al., 2009) and can be reused by treating these waters.

Within the characteristics of treatment technologies to which we refer (low cost and easy maintenance) green walls are very promising systems. These vertical biofiltration systems (Green Walls) are constituted by a vegetation supporting structure and a biofilm growth filtering filler, which is connected to a wall, with a treated water collection system, represent a potential solution to be used in urban centers with the problem of lack of space.

In addition to the direct benefit of using this resource, the development of these technologies brings a large list of other advantages, such as improving the urban landscape through more green spaces, CO_2 reduction and O_2 production, creation of new microclimates, insulation of houses and the increase of biodiversity in urban environments. If this concept could be applied on a large scale at a city level, it could significantly reduce dependence on wastewater treatment plants and the entire adjacent structure, thereby reducing costs in this sector (Masi et al., 2016).

Several studies have shown that such systems are low cost and a very sustainable alternative, contributing to the green growth of a city (Fowdar et al., 2017).

1.2. Objectives

In the scope of this master's thesis is intended to study the operation of a system with the above characteristics, namely a bed of macrophytes with vertical flow (Green Wall) for treatment of greywater, through a small scale laboratory model, with the aim of studying the feasibility of a large-scale facility at the level of institutions characterized by the production of significant volumes of greywater, such as gyms, large companies, large commercial areas and educational establishments.

To that end, it was necessary that the study also includes a detailed characterization of the resource to be used, with the intention of mastering the knowledge of this and verifying if these waters have characteristics that fit in a general context. Thus, domestic and institutional greywater samples were collected and analysed in detail throughout the study.

In order to achieve the stated objective, several tests were carried out not only to characterize greywater but also to analyse the efficiency of pollutants removal, including the influence of the filling medium, which serves as a filter medium, and the importance of vegetation in the process.

The target parameters for analysis include pH, total suspended solids (TSS), volatile suspended solids (VSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen (N), phosphates (P) and pathogens, among others.

2. RELATED WORK

2.1. Greywater Characterization

2.1.1. Greywater Quantity

The quantity of gray water is directly related to the daily habits of the populations. As such, there are many factors that influence the greywater average used daily. The variables involved are the life styles and needs of individuals and communities, parameters such as age and gender of the populations, geographic location and degree of water abundance. Because it does not depend only on one factor, the average consumption can vary from 90 to 120 L / day per person in developed countries, and from 20 to 30 L / day per person in developing countries (Li et al. 2009). This difference is clearly due to the scarcity of possessions and the difficulty of access to this resource.

According to Vieira et al. (2002), effluents that translate into greywater (baths, washbasins, washing machines) account for 60% of a total of water used daily. The fact of having this percentage of greywater volume can translate into more than 40% of waters with low organic load available to be reused with or without treatment depending on the type of use assigned to them.

2.1.2. Greywater Quality

When talking about water quality in general, there are many variables that must be taken into account in order to understand what kind of use or treatment should be applied. It is essential that this analysis be carried out because this resource is directly linked to issues of great importance such as public health and the well-being of societies.

As such, to ensure that greywater meet the quality standards, it must be evaluated on pH, organic matter (BOD_5, COD), suspended solids (TSS and VSS), nutrients (N and P) and pathogens. The importance of the above-mentioned parameter list may vary with the type of target these waters may have after treatment.

The substances present in the greywater generally result from personal hygiene products, detergents, hair and skin, particles of dandruff and dirt from clothing, all of which are easily biodegradable. This biodegradability makes the treatment cannot be very delayed, since reactions that cause bad smells and discomfort can be triggered (Valente Neves and Silva Afonso, 2010).

Although not without treatment, these waters contain much lower concentrations when compared to domestic wastewater. Table 2.1 shows this difference in relation to some parameters.

Table 0.1 - Comparison of characteristics of greywater and domestic wastewater

Parameters	Units	Untreated Greywater	Wastewater
pH	-	7.24 –8.34	-
COD	mg/L	216–320	1050
BOD	mg/L	68–120	450
TSS	mg/L	240–280	503
COT	mg/L	23–36.48	-
N (total)	mg/L	17–28.82	70.4
NO3 - N	mg/L	12.32–7.84	-
P (total)	mg/L	2.934–3.84	17.3
NH4 - N	mg/L	10.28–14.56	-
FC	UFC/100ml	50–120	-

[a] Adapted from Ramprasad et al. (2017)

[b] Adapted from (Metcalf & Eddy, 2002)

2.2. Guidelines

In most countries, specific regulations or standards for greywater reuse are not available or are insufficient (Gross et al., 2007). However, although these types of waters are relatively uncontaminated, there are parameters, such as those previous referred, and values to be taken into account depending on the final destination of treated water, to avoid undesirable public health issues and contamination, among other possible problems.

Worldwide, there are a variety of organizations that support causes related to water scarcity, of which one stands out which promotes the particular study of greywater reuse. The World Health Organization is responsible for the release of four volumes with guidelines for the safe use of wastewater, sludge and greywater. As the organization's own name indicates, it is essentially geared to meet global health needs. Nevertheless, these guidelines are intended for the safe use of these sources within the agriculture and aquaculture sectors (World Health Organization, 2006).

It should be noted that only Australia contains legislation directly related to the use of greywater, where some are presented in table 2.2. A report (BIO by Deloitte, 2015) states that standards and guidelines provide an appropriate methodology in this country, so that cost-effective treatment is applied to a source of water with characteristics appropriate to the intended use. The standards are governed by 7 categories of different uses, including residential and commercial uses, toilet flushing, irrigation and gardening, car washing, plumbing and other water systems and municipal uses such as road washing, control of dusts and irrigation of public gardens, among others.

Table 0.2 – Treated Wastewater reuse standards.

Uses	BOD_5 (mg/L)	CQO (mg/L)	SS (mg/L)	EC (UFC/100ml)	References
GWA					
Subsurface Irrigation	<20		<30		(Government of Western Australia (GWA), 2010)
Surface Irrigation	<20		<30	<10	
Toilets Discharge	<10		<10	<1	

Adapted from (Arden and Ma, 2018; Ghunmi et al., 2011)

2.2.1. Greywater treatment technologies

Research on the treatment and reuse of this type of water has been reported since the 1970s (Pidou et al., 2007). The technologies that currently exist are described by physical, chemical and biological processes (Gorgich and Formigo, 2016; Li et al., 2009; Pidou et al., 2007). The first treatment technologies to be studied and developed were essentially for the physical treatment, which is described, for example, by filtration processes. Even at this stage, processes of disinfection of these waters were already introduced along with the physical processes studied. However, they were only developed and installed in private homes in the early 1990s.

During this period, investigators began to study and develop technologies based on biological processes, among which are biological disks, biological filters and aerated bioreactors. In the late 1990s, the study of more advanced and low-cost technologies such as membrane bioreactors and built wetlands emerged (Pidou et al., 2007). Regarding chemical processes, the available literature is much lower and these include only a few treatments, namely, coagulation processes, photocatalytic oxidation, ion exchanges and granular activated carbon (Li et al., 2009).

These combined technologies are part of the entire greywater treatment process, which is divided into three essential phases: pre-treatment, main treatment and post-treatment.

Pre-treatment, which may be composed of septic tanks, screening or filters, is fundamental in reducing larger particles and oils and fats, thus avoiding a subsequent clogging in the installation (Gorgich and Formigo, 2016). After treatment, disinfection of the treated water is necessary so that the normative values in relation to the content of pathogens are fulfilled (Li et al., 2009).

Several greywater treatment schemes have been installed around the world but there are no specific trends regarding treatment types and geographic locations. However, it is expected that developing countries will adopt low cost and maintenance technologies due to economic issues (Pidou et al., 2007).

3. MATERIALS AND METHODS

3.1. Greywater characterization

3.1.1. Samples Sources and collection

In the present study, the characterization of greywater had a greater focus on domestic and institutional waters. The option for the first strand is the fact that it is easy and accessible to collect, since these waters are produced daily in our homes. In the case of institutional waters, their collection entailed the creation of a system to obtain the necessary samples for the study in question.

The collection was based only on the waters of baths and washbasins of bathrooms, from three different residences. With these sources it was possible to estimate the volume per use at each collection. In the case of baths and because they are always collected from the same baths, the volume was estimated from the flow rate of each tap and the duration of each bath. As regards the volumes of the washbasins and because they were significantly smaller, discharges were made to a container and counted manually from a measuring cup. As noted above, the collections were made separately, in washed containers.

Parameters and methods

The present study aimed to analyze all the necessary parameters to guarantee the norms of reutilization of treated gray water. For this reason and at an initial time, it was proposed that the samples be analyzed for the following parameters: pH (YSI-556 Multiparametric Probe), COD (Standard Methods), BOD_5 (Standard Methods), TSS (Standard Methods), VSS Methods); Total N (Colorimetric Kits); Total P (Colorimetric Kits); Total and fecal coliforms (Standard Methods), dissolved O_2 (YSI-556 Multiparametric Probe) and electrical conductivity (YSI-556 Multiparametric Probe).

3.2. Green wall Characterization

3.2.1. Structure

The objective of this study is essentially to test the feasibility of a green wall in the treatment of the above characterized waters. For this reason it was fundamental to develop a laboratory skeleton with conditions that allowed studying the intended.

The company Minigarden, LDA is known in the market as a supplier of vertical gardens, prepared for horticulture in small spaces. The various types of structures are sold in modules and can be adapted to any space. As such, the company was contacted to obtain a 3 by 3 module, consisting of three compartments with horizontal connection vertically separated by lids that allow accumulation of water to feed the plants placed in the upper line.

To evaluate the treatment of greywater on a green wall, it is essential to create variable parameters within certain conditions making it possible to compare different situations. As such, the original structure was adapted in order to obtain three different treated effluents.

3.2.2. Medium

Options and Selection

Initially it was thought to test different means of treatment to later decide on what would make the system more efficient and sustainable. The alternatives initially considered included an abundant material in Portugal, cork, available by the company Amorim Cork Composites and a biological filtering material, porous ceramics.

Although cork is a little known material in the water treatment industry, there have been some advantages in testing this material, namely because it is light and because it has porosity and a favourable surface area for biofilm growth. Two different sizes were available for the test, one with sandy aspect and one with larger dimension. The coarse granulometry, with sizes between 4 and 5 mm, corresponds to granulated cork. The fine particle size corresponds to the outer part of the cork plates, has a low economic value and is used only for firing in ovens during the cork treatment process.

The other option would be to test the porous ceramic (Siporax), with known results in the treatment of water, very associated with maintaining the cleaning of aquariums. However, this material could bring an added cost to the installation, moving away from the objective of keeping the system sustainable.

Methods

The chosen filler medium was subjected to various procedures before being placed into the structure. The procedures in question were instrumental in understanding how cork would behave when the whole system was in place. Within the various processes for testing this treatment medium are tests for their porosity (total and effective) and permeability. It was also found necessary to make some physical changes to the material, which would complement the study and are described later.

3.2.3. Vegetation

The process of identifying the vegetation to be used in the system was essentially related to the collection of information from other similar studies. It is essential that the chosen vegetation is resistant to fluctuations in the conditions of the system and especially that it is easily adapted to humid environments.

After the research, four different plant species, with the characteristics mentioned above, were identified, namely *Ophiopogon planiscapus* (Niger), *Asplenium*, commonly known as fetus, *Ficus repens* and finally *Chlorophytum comosum*. The study of the influence of vegetation in the treatment of greywater is a very important aspect of the work. In this way, it was understood that it would be relevant to analyse which species would have the greatest capacity for treatment. Since the system consists of 3 columns, we chose to test 2 species, one in each column, and the third would be constituted only with the filling medium functioning as the control. The species *Asplenium* and *Chlorophytum comosum* were chosen and placed in the system.

3.2.4. Experimental design

The laboratory system, after all the tests underlying its altered structure and the filling medium, was assembled in its entirety. The general basis of the system is a wall of 3 columns and 3 rows (i.e. 9 pots) with the flow running vertically separately in each column. The wall is 65 centimeters wide, 58 centimeters high and 14 centimeters deep.

Each pot was filled by the filling medium, in this case cork, along with vegetation indicated for the treatment of water. Once 3 cork granulometry is available, each compartment was formed with the following description: The larger particle size was placed at the base with a thickness of about 3cm, the cork obtained from the crushing followed by the highest representativeness (7cm) and finally the cork with a sandy appearance at the top that functioned as a support for the vegetation with 4cm. This structure was based on the study developed by Fowdar et al. (2017).

The arrangement of the materials in this way contributes to the better functioning of the system and treatment of the tested waters. It should be noted that at the bottom of each pot, before any filling medium, a net was placed which prevents clogging of the water passage means and improves hydraulic performance.

Each column counts with an entrance and exit of water, both connected to a reservoir to store the effluent of each of these. The inlet of water in each column is also assisted by a pumping system, thus making a total of 3 reservoirs and 3 pumps. Recirculation is guaranteed in each column by the characteristics described above and thus higher treatment efficiencies are expected.

3.2.5. Experimental procedure

The columns were fed with the domestic samples collected from baths and washbasins with a regularity of 2 days per week, until October 2018. Although the 2 replacements were always maintained weekly, there was some variability on the chosen days of the week which led to a variation of the hydraulic retention times. The study of the laboratory system lasted 4 weeks and the samples collected were submitted to a preparation before being included in the system.

The preparation consists of creating a composite sample with 15L, having an actual proportion of bath water (about 70%) and lavatory (30%). Before being divided by the 3 reservoirs, a volume was collected for the analysis of suspended solids and COD and some general parameters such as pH, temperature, hydraulic conductivity and dissolved oxygen were also counted. After this procedure 5L were inserted into each previously leaked reservoir and then the pumps started to run.

In the case of the system effluents, the volumes were measured when they were removed from each reservoir in order to evaluate the evapotranspiration of the system. Homogeneous samples were also taken for the study of the same parameters evaluated in the affluent, guaranteeing the possibility for comparison between the effluent and the effluent of the system. The treatment efficiencies were then obtained from the comparison of these parameters.

Prior to the operation of the plant, the feed rate was expected to be approximately 7 ml / min. However, it was necessary to evaluate the power of the pumps and monitor the output flow to try to adjust this parameter during the 4 weeks.

It was followed not only the release of color by the filling medium but also the evolution and adaptation of the vegetation chosen for the system. This monitoring allowed to conclude some aspects, later referred to, of great interest for future studies in relation to the installation.

4. RESULTS AND DISCUSSION

4.1. Greywater Quality

4.1.1. TSS and VSS

The results of the suspended solids present in the collected samples were submitted to a statistical treatment of the data, obtaining table 4.1, in order to evaluate, in a general way, the impact of this parameter on the greywaters analyzed.

Table 0.1 – Statistical results of TSS.

	Total Suspended Solids (mg/L)			
	Bath	**Tooth Washing**	**Hand Washing**	**IST Lavatory**
Nr Samples	36	44	29	6
Average	39.37	159.46	80.89	17.83
Minimum	4.77	14.33	8.04	11.20
Q1	10.48	110.59	21.01	13.75
Median	14.40	149.34	65.44	16.30
Q3	41.82	195.09	149.81	17.20
Maximum	325.56	298.89	203.78	32.80
Standard Deviation	70.73	68.59	68.43	7.71
Variation Coef.	1.80	0.43	0.85	0.43
Asymmetry Coef.	3.67	0.28	0.61	1.93

From this table it was also possible to obtain a dispersion graph (Figure 4.1), which directly compares all the values obtained showing the significance of each source in this parameter.

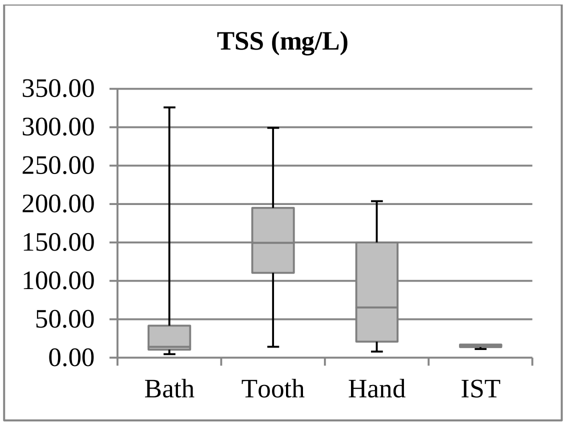

Figure 0.1 – Statistical dispersion graphs of the samples in relation to the parameter TSS.

Thus, it is possible to conclude that, in relation to the TSS present in the samples, tooth washing is the source that has the highest concentration. Although there was a greater variation of values in the bath effluents, confirmed by the values of the coefficients of variation and asymmetry, reaching 325 mg/L of solids, the effluents of the tooth washing were on average higher in comparison with the others sources. These results relate to the fact that the hygiene products used in this source have a high concentration of solids derived from fluorine, calcium and sodium and also some microplastics which may be present.

Another fact that justifies the solids content in this source has to do with the volume of water per use. While in the baths water consumption is around 45L, significantly diluting the solids that may arise, tooth washing has a consumed volume of only 1.5L on average, thus concentrating high solids content in the samples collected.

It is also verified that, although the number of samples is not very representative, the effluents analysed from the IST lavatory show very low values when compared with the other sources. The average value of this source is below the standards presented, for the represented purposes, showing excellent qualities for its reuse.

The same statistical analysis was used for the case of VSS, shown in table 4.2. The samples are necessarily the same as those analysed in the TSS, being possible a direct comparison with the values presented previously. It was also possible, through these values, to obtain the VSS/TSS mean ratios of baths, tooth washing, hand washing and the IST lavatory.

Table 0.2 - Statistical results of VSS.

	Volatile Suspended Solids mg/L			
	Bath	**Tooth Washing**	**Hand Washing**	**IST Lavatory**
Nr Samples	36	44	29	6
Average	25.26	45.86	68.89	14.64
Minimum	4.85	13.13	7.11	11.20
Q1	9.37	28.29	19.69	12.17
Median	12.88	41.93	53.68	14.00
Q3	40.35	58.74	127.04	14.83
Maximum	112.22	107.78	169.78	22.00
Standard Deviation	24.58	25.23	57.46	3.90
Variation Coef.	0.97	0.55	0.83	0.27
Asymmetry Coef.	1.90	0.87	0.59	1.68

Table 4.2 shows that tooth washing is not the most representative of SSV and that in this case it is handwashing. We again resorted to a graph of dispersion of the samples of each effluent, shown in figure 4.2.

It was observed that the majority of VSS comes from the washing of hands reaching values that are around 160mg/L. In relation to this source it is also verified that these values are very close to the values described previously in relation to the TSS. The same is true for IST lavatory and bath effluents. This means that the VSS/TSS ratio is very high, averaging above 80%, indicating a high organic load concentration in this type of effluent. Although tooth washing has a much lower VSS/TSS ratio, about 30%, it does not imply that its contribution in organic load is lower. As can be seen, the concentration for this parameter is still higher than the IST lavatory and bath effluent.

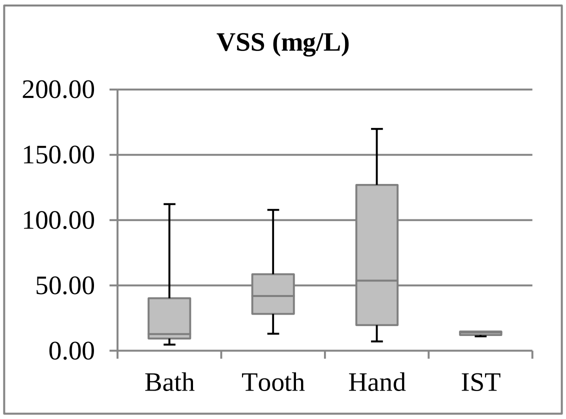

Figure 0.2 – Statistical dispersion graphs of the samples in relation to the parameter VSS.

4.1.2. COD

The results obtained were in relation to the COD parameter were included in the same way as the solids. For this parameter the analysed sample volume was different from the previous parameter.

From the analysed samples, table 4.3 indicates that, once again, tooth washing is a source with more COD, followed by tooth washing, bath water and finally, with very low values, the effluent of the IST washbasin.

Table 0.3 – Statistical results of COD.

	COD (mg/L)			
	Bath	**Tooth Washing**	**Hand Washing**	**IST Lavatory**
Nr Samples	42	52	27	6
Average	125.13	378.56	261.76	78.06
Minimum	5.44	106.41	13.20	43.49
Q1	62.33	225.05	136.75	58.25
Median	128.08	291.26	226.67	66.02
Q3	177.48	461.77	351.84	103.49
Maximum	294.36	977.85	772.03	121.16
Standard Deviation	68.74	243.75	171.35	32.18
Variation Coef.	0.55	0.64	0.65	0.41
Asymmetry Coef.	0.33	1.36	1.01	0.68

The values of the table obtained the graph shown in figure 4.5, where it is possible once again to analyse the results in a comparative way between the different effluents.

It should be noted that the data collected from the bath water show a very small variation, however in relation to the sources of the domestic lavatories, this variation is much more pronounced. Regarding the IST lavatory, it is verified that the values obtained were the most constant and therefore their variation is much lower in relation to the other sources, however the volume of samples was also much lower, counting on only 6 samples.

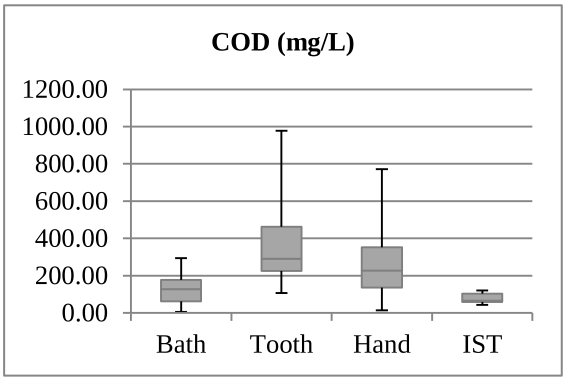

Figure 0.3 – Statistical dispersion graphs of the samples in relation to the parameter COD.

In sum, the values obtained correspond to those expected and only tooth washing is above the values presented in table 2.1. However, since the values in this table correspond to a mixture of greywater, if we consider a mixture of the three domestic effluents with the respective proportions in relation to their consumption, there would be a dilution of this source causing the mixture to approach the presented values in Chapter 2.

4.1.3. BOD_5

In the case of the parameter of BOD_5 there was only availability to test this parameter once. The tests were carried out on samples from all sources, making a total of 4 different samples tested. The obtained values are available in table 4.4, along with other parameters obtained in relation to the same samples. Thus, it was possible to analyse the relationship between BOD_5 and other parameters so that it was possible to have a perception of how this factor would be present in the other untested samples.

From a first analysis of the table, the samples tested indicate that handwashing would be the most representative in the contributions of this parameter, followed by bath effluent, tooth washing and, finally, the IST lavatory.

However, it can be seen that the BOD_5/COD ratio is close to 0.5 in all sources and it is believed that tooth washing would continue to be the more relevant with regard to BOD_5, since it presents COD values normally higher than the one obtained in this sample. Thus it is not possible to conclude concrete facts regarding this parameter and the respective sources.

The BOD_5/COD ratio is also a good indicator in biological treatment. The values obtained indicate that these waters have a strong potential in this type of treatment. It is expected that, if the filling medium meets expectations in biofilm growth, favourable treatment efficiencies are achieved.

Biological treatment in this type of effluent is necessary since all BOD_5 values are above the standards presented, although the value for the IST lavatory effluent is close to the normative value.

Table 0.4 – BOD5 results of a sample from each source and associated values of the remaining parameters.

Parameter	**Units**	**Samples**			
		Bath	**Tooth**	**Hand**	**IST**
BOD_5	**mg/L**	134.0	127.0	265.0	39.0
COD	**mg/L**	261.0	227.6	453.6	88.5
TSS	**mg/L**	40.0	28.9	37.1	14.8
VSS	**mg/L**	36.5	11.1	28.1	14.7
pH	-	7.7	7.9	7.9	7.2
ORP	**mV**	206.0	194.5	194.5	236.0
T	**ºC**	25.3	22.2	22.3	23.3
EC	**µS/cm**	335.0	309.0	324.0	421.0
DO	**mg/L**	5.1	6.6	6.5	1.7

4.1.4. Microbiological pollutants

The content of pathogens, more specifically bacteriological agents E. coli and Enterococcus, very present in the gastrointestinal tract of the human body, were obtained only once, in a total volume of 10 samples. The results obtained from the IST analysis laboratory are shown in table 4.5.

It is observed that tooth washing is again the source with the most worrying values. The origin of these values may be that this effluent contains saliva and is directly in contact with one of the largest sources of pathogens in our body. Another relevant aspect that can justify the contents presented will be the plume created by the sanitary discharges that with a range of about 2 meters can contaminate the toothbrushes present in the same space. However, the values obtained between different residences in the same source show some variation. The same is true for bath effluents, but in this case the concentrations are lower.

IST and handwashing effluents are curiously low. Handwashing and the products used therein have the ability to greatly reduce these bacteriological agents. Throughout the study, it was also verified that the IST lavatory effluent had a characteristic smell of bleach resulting from the daily cleaning of lavatories, indicating that this product could be the main reason for the reduction of pathogens in this source.

Table 0.5 – Analyses results of E. coli and Enterococcus in 10 different samples.

Sample	Description	*E. coli* (ufc/100ml)	*Enterococcus* (ufc/100ml)
1	Bath 1	700	$>10^5$
2	Bath 2	300	$>10^4$
3	Bath 3	160	2
4	Tooth Washing 1	2800	$>10^6$
5	Tooth Washing 2	0	$>10^4$
6	Tooth Washing 3	82	0
7	Hand Washing 1	35	6
8	Hand Washing 2	0	0
9	Hand Washing 3	0	0
10	Lavatory IST	49	0

In conclusion, the results obtained showed that it is essential that these waters are subject to a disinfection treatment that ensures that the water is reused safely, without affecting the others.

4.2. Performance of the Green Wall in the treatment of greywater

The preparation of the adaptation of the green wall began with tests to characterize the filling medium, and adaptation of the Minigarden system. After all the testes are completed, it was possible to start the operation of the proposed system. The system was monitored for 4 weeks, with the affluent being replaced twice weekly. On the replacement days, both input and output samples were analyzed in each reservoir. Tests carried out included the counting of the inlet and outlet volume in each tank, the content of the samples in relation to suspended solids and COD and other general parameters such as temperature and pH of the samples, for example. There was also a control of the evolution of the color of the effluent, to guarantee that the cork would lose the same, and also of the growth and adaptation of the vegetation.

4.2.1. Characterization of the filling medium

Porosity

The first tests carried out to evaluate the filling medium and its treatment capacity were the total and effective porosity. This parameter indicates the ability of the medium to store water in its pores.

It was observed that cork is a very porous material, since both calculated porosities are around 50% pore volume. These results demonstrate that the medium chosen has a great ability to retain water and consequently may have positive effects on the treatment. The porosity of this material is also favorable for biofilm growth since it has a high contact area.

Permeability

The permeability associated with this material was a relatively difficult factor to obtain. The first tests demonstrate that the values of this parameter would be very high and was necessary a more efficient method to calculate it. The results were achieved through the constant head permeability method present at IST's Geotechnical Laboratory.

The results obtained, using the mentioned method, rely on the cork of greater size and for the smaller dimension, available by the company Amorim.

As expected, a high value was verified in relation to the larger particle size. The water percolates through the filling medium with a permeability of 2.1 cm/s, indicating that it moves very rapidly therein. In the case of smaller particle size the values obtained were more favorable. Still, a permeability of 0.7cm/s is a high result.

The fact that we have high permeability can compromise the greywater treatment, since the hydraulic retention time will be relatively low. For this reason, the treatment system adopted is supported by recirculation of the effluent, thus increasing the residence time being more likely in the treatment.

4.2.2. Influent and effluent volumes

It was verified that the system was subject to evapotranspiration and water retention, because the output volumes were always lower than the input ones. This may have been aggravated by the fact that the tests were carried out during the end of the summer, and therefore it is expected that with the lower winter temperatures the output volumes will increase.

Table 4.6 shows the average results for the inlet volumes, which were the same in all reservoirs, and output. It is verified that the output volumes were also very similar and therefore there were no significant differences regarding the evapotranspiration that occurred in each treatment line.

Table 4.6 - Average volumes of input and output of each reservoir and its evapotranspiration%.

	Inlet	Outlet	% Evapotranspiration
Avg Volume R1	4.43	3.85	13%
Avg Volume R2	4.43	3.76	15%
Avg Volume R3	4.43	3.81	14%

4.2.3. Suspended solids

As previously mentioned, feeds were carried out twice weekly but there was a variation of the days chosen which resulted in different hydraulic retention times. For this reason the results and the removal efficiency of suspended solids were analyzed for each feed.

Table 4.7 shows the results obtained for the suspended solids in the influent samples and their respective effluents in each reservoir, associated to each column of the system. Clearly, the quality of the effluent depends directly on the solids content of the system. The higher the solids content of the inlet, the higher the output content.

However, most of the influents tested have low concentrations, which normally translates into reduced output values that are below the standards presented for restricted uses of this treated water (<30mg / L).

The averages indicated in table 4.7 shows that the reservoir 2 is the one with the lowest concentrations of suspended solids followed by the reservoir 1 and finally the reservoir 3. It is noted, however, that the differences between the three treatment lines are not significant.

Table 4.7 – Inlet and Outlet Quality in relation to TSS.

	TSS (mg/L)			
HRT	**Influent**	**Effluent R1**	**Effluent R2**	**Effluent R3**
6 days	42.8	9.6	9.6	21.9
2 days	91.3	47.2	52.7	33.9
5 days	88.2	12.4	13.3	9.1
4 days	41.3	13.7	15.3	18.0
4 days	45.8	14.8	8.8	55.9
4 days	48.5	31.1	8.3	9.7
Avg.	59.6	20.3	17.8	23.7

An analysis of the data obtained in terms of treatment efficiencies was used (table 4.8), and it was verified that effectively the column of the system that discharges into reservoir 2 would be the most efficient in removing solids from the inlet.

It is also verified that the reservoir 2 presents the most constant values, except when the system was submitted to only 2 days of recirculation. In this case the output solids contents were much higher, having a negative impact on the calculated means. In reservoir 3 a negative efficiency is observed which greatly influences the results of treatment of the associated column. The reasons which may justify the solids content at the outlet being higher than the input can be justified with some leaching of the smaller filler.

Table 4.8 – Removal efficiencies of TSS in each system column.

	Removal Efficiencies %		
HRT	**R1**	**R2**	**R3**
6 days	-	-	-
2 days	77.6	77.6	48.9
5 days	48.3	48.3	62.9
4 days	85.9	85.9	89.7
4 days	66.7	66.7	56.4
4 days	67.7	67.7	-21.9
4 days	35.9	83.0	79.9
Avg.	63.7	71.5	52.7

In short, the efficiencies obtained were sufficient to obtain the normative values stipulated in chapter 2, if we do not consider the anomalous values. The medium used and the green wall structure allow filtration of these and since the content of VSS in these waters is quite high, the reduction of the solids may also be associated to the biological treatment. As the study progresses, it is expected that efficiencies may increase and that the values obtained will be more constant.

4.2.4. COD

The results obtained in relation to the performance of the system in reducing the COD of the influent are presented in table 4.9. Since the standards defined in Chapter 2 do not cover this parameter it is not possible to conclude whether the treatments were sufficient to guarantee the quality of the effluent in relation to this parameter.

Table 4.9 concludes that the effluent from the reservoir 1 was the one that presented the largest reduction of COD in comparison with the inlet of the system, following the reservoir 3 and finally the reservoir 2. The reservoir 1 was the one that showed the lowest variation of the results, thus having the least volume of anomalous results which contributed to the fact that its average content was lower than the other reservoirs.

Table 4.9 – Inlet and Outlet Quality in relation to COD.

COD (mg/L)				
HRT	**Influent**	**Effluent R1**	**Effluent R2**	**Effluent R3**
6 days	205.0	202.7	215.9	234.6
2 days	75.3	83.9	109.5	205.0
5 days	428.7	92.4	83.9	82.3
4 days	269.5	41.2	31.1	64.5
4 days	115.7	26.4	29.5	45.0
4 days	188.7	38.1	10.9	84.7
4 days	177.1	68.3	390.7	10.1
Avg.	208.6	79.0	124.5	103.7

Translating the previous table into removal efficiencies, it was possible to obtain table 4.10 that represents exactly these values. Some of the results obtained have efficiencies around 80%, but these results are conditioned by the negative values present.

Table 4.10 - Removal efficiencies of COD in each column.

Removal Efficiencies %			
HRT	**R1**	**R2**	**R3**
6 days	1.1	-5.3	-14.4
2days	-11.3	-45.4	-172.2
5days	78.4	80.4	80.8
4days	84.7	88.5	76.1
4days	77.2	74.5	61.1
4days	79.8	94.2	55.1
4days	61.4	-120.6	94.3
Avg.	53.1	23.8	25.8

One way to increase these values is to continue the studies carried out. In this way, it will be possible to obtain a larger volume of results, reducing the impact of these values out of normality. However, taking into account the duration of these tests (4 weeks) it is appropriate to mention that this system is promising.

4.2.5. Influence of vegetation

During the assembly phase of the system two different types of vegetation were inserted, in columns 1 and 3 of the green wall. In the first column were placed fetus in all 3 pots and the third column counted with the specie *Chlorophytum comosum*. The system worked continuously and with recirculation, therefore these plants would have to adapt to a constantly saturated environment and extreme conditions.

It was observed that during the adaptation phase of the system the fetus developed even though they were subject to this type of conditions. The species used in the third column did not withstand the same environment conditions and start degraded after 1 week. After this event it was decided to keep only the first column with vegetation.

Thus, it is concluded that only one of the species chosen may be promising in the treatment of greywater, if we consider the above conditions. Because only one species was used during the 4 weeks, it was not possible to conclude relevant results regarding the influence of vegetation in reducing pollutants. However, it is known that the vegetation has a greater contribution in the removal of nutrients, which for the present study were not analyzed, due to lack of available means.

5. CONCLUSION

The dissertation was developed with the motivation that there is a need to combat one of the world's adversities, such as access to drinking water. The structure developed sought to contribute to the studies developed in this area, in the sense of minimizing this problem. Thus, with the time available, the present study was organized in order to cover the most relevant aspects and to elaborate a detailed procedure for the creation of a viable greywater treatment system.

To understand the level of treatment required for this type of effluent, it is critical to understand and characterize greywater. As such, the methodology described above begins by defining the type of samples and collection for the study.

In relation to the characterization of the resource in terms of quality, the values obtained referring to all the parameters tested are in the range of the expected values. Although some parameters have been tested only once, such as the case of BOD_5 and pathogens, it was possible to draw relevant conclusions for the study. Through the results obtained from BOD_5 it was possible to estimate the BOD_5/COD ratio in all sources. All had a ratio close to 0.5, which is a good indication that the treatment adopted could be viable. The results of pathogenic microorganisms served to confirm that this type of effluent does not dispense a phase of disinfection treatment.

The values of SST, SSV and COD confirmed the low concentration of pollutants in this type of waters, although some sources show a marked variation of values with higher results than the expected values, but on average the values were very satisfactory.

The analysis of greywater quality also served to understand the contributions of each source analysed. Tooth washing to have a strong impact on all analysed parameters, however, if it is considered the volumes of each source in a mixture of greywaters, the bath effluents would dilute these values, thus balancing the values. It is also believed that tooth washing, due to the products used, would be the most representative in terms of emerging pollutants resistant to degradation. The samples from the IST lavatory analysed showed very low values regarding the parameters studied. In many cases the quality of this effluent was already below the stipulated normative values.

Concerning the characterization of the medium, it is concluded that its porosity was quite favourable to allow the biological growth and, consequently, the treatment of the waters that would feed the system. However, the high results obtained in terms of its permeability, demonstrated that the treatment could be compromised by not having an adequate HRT. This has led to the consolidation of the need for the treatment system to be accompanied by the recirculation of the inlet.

After all aspects of the system were studied and the system was submitted to the final assembly, its SS and COD removal efficiencies were monitored. It was noted that the system initially had negative efficiencies, which would be expected since it would always have to undergo an adaptation phase. There was a positive evolution in the removal efficiencies of solids and COD reaching results higher than 80%, which shows the viability of the green wall in the treatment greywater. However these parameters still present some episodes with anomalous efficiencies, that only more prolonged studies can help to analyse.

The influence of the vegetation placed on the system was difficult to analyse. There were no significant differences between the performances of each column and the specie assigned to column 3 was not resistant to the conditions of the system. Normally, vegetation is responsible for the uptake of nutrients such as nitrogen and phosphorus, but it was not possible to analyse these parameters at the time of the study.

It should also be noted that the changes made to the skeleton of the system, provided by Minigarden, did not show any leaks over the study time, guaranteeing adequate conditions for the study.

In conclusion, the whole system was very promising. Although, in the course of the study, it has been concentrated efforts to define an adequate methodology to support the assembly of the system and because it is a work never before investigated in the scope of a master's dissertation at Instituto Superior Técnico, the results obtained in only 4 weeks corresponded to those expected. It will be necessary, however, to continue the studies carried out to date, so that the results are further consolidated.

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