Adaptation of green walls to the treatment of greywater with recycled materials

David Martins

david.hildalgo@ist.utl.pt

Instituto Superior Técnico, Universidade de Lisboa, Portugal

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ABSTRACT: The increase of the world population and the consequent increase in the consumption of water plus the increase in urban and domestic wastewater, lead to the need to find new means that reduce the pressure generated on water resources and wastewater treatment systems. One of the means that has been gaining more and more emphasis is the use of green walls for the treatment of greywater.

This dissertation aims to study the feasibility of a laboratory scale green wall, adapted for the treatment of greywater (GW), focusing in analyzing two important elements of the system, filling media and plant species. For each of these elements, two different solutions were used, the filling medias used were ceramic tiles with coconut fibers and textile fibers. Regarding the plants, the species used were Adiantum capillus-veneris and Asplenium onopteris. An analysis was carried out for each type of filling medium and the influence of each plant species in each one, in order to identify the effects they may have on the removal of pollutants.

The installation of green walls with filling media of ceramic tiles and coconut fibers with the Asplenium onopteris species, presents an enormous potential for the treatment of greywater, but it can still be optimized. Textile fibers are a good material for retaining suspended solids, but they are not suitable material for plant installation.

1. Introduction

Due to the growing scarcity of potable water and the continuous growth of the world population and its water consumption, it becomes necessary to find new ways to balance the increasing pressure on the environment and its water resources, in order to meet the needs of the human being and ensure sustainable growth without jeopardizing the future of future generations.

According to UNICEF, around 35% of the world's population doesn’t have access to clean water and 43% of the world does not have access to basic sanitation services, making them exposed to diseases such as typhoid fever and cholera. According to the WWF (world wildlife Fund for Nature), 2 million people die every year, most of them children, from diarrhea due to lack of water and sanitation.

The reuse of wastewater has enormous potential, particularly in urban areas where it has an approximately continuous flow of production, which can be used for various non-potable purposes, such as cisterns or fire systems. GW represents around 70% of domestic consumption, the reuse of these would be a solution that would substantially reduce the pressure on drainage and treatment systems.

GW is designated as domestic wastewater with the exception of water from toilets. Some authors consider that water from kitchen sinks and washing machines and dishwashers is not considered due to its high concentration of organic matter, oils, fats, clothes fibers and detergents, requiring further treatment. As such, GW can be divided into Light greywater and mixed which then contain water from kitchen sinks and washing machines and dishwashers (Arden & Ma, 2018; Boano et al., 2021; Ghaitidak & Yadav, 2013).

2. Experimental Setup

2.1 Green wall characterization

The green wall used was an adaptations of a green wall solution model from Minigarden, LDA, which was adapted to the flow conditions required for this study. The wall is made up of two independent modules, each module has three distinct level connected vertically.

On each level there are three pots that were vertically separate by PVC sheets glued with silicone glue, to prevent water from circulating horizontally between each pot, with water flow being done only vertically, forming three independent vertical lines of flow in each module.

Also, at the base of each level, were made holes to improve the flow between each one level. In addition to that, at the base of each module were also made holes to introduce outlet pipes so GW can flow to the exit buckets to later be collected.

The module on the left, module 1, contains line 1 to 3 and the module 2, on the right, contains line 4 to 6. Each line is numbered from left to right (Figure 1)

Figure 1 – Green wall studied.

2.2 Filling media

The felling media works mostly as a primary treatment system, as a filtration process, and as support for the vegetation. In this type of systems, green walls, it is necessary to use light materials, so their weight doesn't jeopardize the stability of supporting structure.

The hydraulic performance of the green wall is directly influenced by the filling media, which consequently affects the quality of the effluent water treatment. The permeability of material has an influence on the type of treatment to which the GW are subjected. Materials with high permeability, will be less likely lead to clogs in the system, water circulates faster through the system, leading to a lower HRT (hydraulic retention time), and the types of pollutant removal are most likely physical-chemical processes. On the other hand, with materials which have a lower permeability will lead to lower HRT, and water will stay longer in the system, allowing the biological processes of pollutant removal degradation to occur, which are responsible for denitrification, reducing N and organic matter(Prodanovic et al., 2017).

In this study, different types of filling media were used. In module 1, were used ceramic tiles with coconut fibers and in module 2, textile fibers. The reasons for this choice were the fact that both filling media are light and can be obtain good values of permeability and because both are recycled materials. To archive the permeability required for this study, were made tests to reach these goals. The combination for ceramic tiles and coconut fiber was, 70% and 30% respectively.

2.3 Vegetation

Plants are the main responsible for the removal of P, N and other types of salts, this mainly by absorving them through their roots. According to (Fowdar et al., 2017), climbing and ornamental plants have enormous potential for green wall-type systems and that fast-growing plants are especially efficient in removing N, plus, they are more resistant to changes in operating conditions such as rest periods, cargo flows and pollutants.

The choice of the vegetation was based on their adaptability to humid environments and its availability in Portugal. Two species of plants were chosen for this study, Adiantum capillus-veneris and Asplenium onopteris. On the left of line of each module (line 1 and 4), was used the Adiantum capillus-veneris and on the right lines (line 3 and 6), was used the Asplenium onopteris.

Adiantum capillus-veneris is a species of fern that is common in Portugal, Azores and Madeira. Asplenium onopteris is also a fern, very common in Mediterranean region and western European coast. Both species tend to inhabit damp and dark places, such as wells.

2.4 Greywater

This study was carried out between July and September, a period marked by the COVID-19 pandemic. Measures to combat the pandemic brought along home schooling, mandatory curfews and quarantines. These measures resulted in a reduced use of IST's sanitary facilities, as such, it was decided to produce synthetic GW instead of collecting it in sanitary facilities.

GW was produced on Mondays, Wednesdays and Fridays. The GW produced on Monday and Fridays was used on the respective day and the following day, with 65L being produced each day. On Fridays, 35L were produced to feed the system just that respective day.

2.5 Flow and test conditions

The pumping system was composed by six pumps, each one feeding only one flow line. As indicated previously, the flow is done vertically, and each line of flow is independent from the others. The flow of each line is different, with middle line (line 2 and 5) having lower flow as the middle have a smaller surface area than the far end pots.

The system was in operation 8 hours a day, 5 days a week, to simulate the use of an 8-hour working day, the period chosen for its operation was from 15:20 to 23:20, from Monday to Friday. Each module of the green wall was fed by the same bucket, two 26L buckets were used, each day being filled with 16L of greywater

3. Results and discussion

3.1 Plant adaptation

The plants were installed on the end of June, and it was necessary to make small holes in each filling media to allow them to be inserted and to be able to partially cover their roots and facilitate the intrusion of the roots into the filling medium

Both plant species had a good adaptation to the system. The Adiantum capillus-veneris was the species that had a faster growth and bigger dimension compared to Asplenium onopteris. In both species of plants, it was possible to observe that some leaves inside each pot became dry and fell since they were not so exposed to the sun.

3.2 Tracer test

To calculate the HRT, several tracer tests were performed throughout the study. Initially, tests were carried out for all lines still without plants, afterwards new tests were carried out for lines that already had plants. At the end of the study, new tests were performed to verify if there were changes in the HRT (Table 1).

Table 1- HRT of each line.

Phase	Units	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6
Without plant	min	147	107	133	75	72	80
Beginning of study	min	125	-	131	173	-	199
End of study	min	102	102	74	128	173	122

Initially, the module with only ceramic tiles and coconut fiber filling media and without plants presented higher HRT values compared to the module with only textile fiber filling medium. After the introduction of the plants in the respective lines, the HRT values became higher in the module with textile fiber filling media (line 4 and 6).

In line 2, with only the filling media of ceramic tiles and coconut fibers, there was no significant variation in HRT throughout the study, but in lines 1 and 3 (with plants) there were variations, and at the end of the study the values decreased significantly in both lines. To introduce the plants, it was necessary to open small holes, which may have favored the appearance of preferential paths. Initially the presence of soil aggregated to the plant roots may have retained this reduction in HRT, but during the study, the dragging of these particles contributed to this reduction in HRT and the opening of new preferential paths.

In the module with filling media of textile fiber, there was a large variation of HRT across all lines for the period of the study. Unlike line 2, line 5 with only filling media had an increase in HRT throughout the study, being the line that presented the highest final HRT value, going from 72 minutes to 173 minutes. The increase in HRT in this module was due the fact that the textile fibers, when absorbing water, became a more compact material creating greater water retention and the textile fibers' own humid environment are favorable to the origin of fungi that retain salts.

3.3 Immediate parameters

The immediate parameters are those that were instantly measured on the same day as the GW were collected, including: PH, electrical conductivity, DO (dissolved oxygen), %DO and temperature (table 2).

Table 2 - Results of the immediate parameters of each line (average ± standard deviation).

	CE (µS/cm)	PH	%OD	OD (mgO^2/L)	T (C^0)
Affluent	643.4 ± 26.8	9.16 ± 0.19	104.5 ± 3.9	8.98 ± 0.43	23.1 ± 1.0
Line 1	680.3 ± 55.1	7.46 ± 0.23	30.1 ± 20.9	2.59 ± 1.80	22.8 ± 1.0
Line2	674.2 ± 52.9	7.45 ± 0.18	22.9 ± 14.8	1.98 ± 1.28	22.6 ± 0.9
Line 3	679.9 ± 56.5	7.42 ± 0.13	29.9 ± 19.2	2.57 ± 1.65	22.7 ± 0.9
Line 4	681.2 ± 58.2	7.51 ± 0.25	38.1 ± 23.6	3.27 ± 2.01	22.7 ± 0.9
Line 5	683.8 ± 66.7	7.65 ± 0.25	57.2 ± 16.6	4.93 ± 1.41	22.6 ± 0.9
Line 6	677.4 ± 57.8	7.58 ± 0.17	47.8 ± 17.2	4.11 ± 1.48	22.8 ± 0.9

In terms of electrical conductivity, the values were very similar between all lines, with no great difference between the type of plants and filling medium. In all lines the values obtained were higher than the EC values of the GW, this is due the fact that the salts present in the GW remain in the system. Initially, the EC values of the effluents were lower than those of the GW affluents in both modules, but as the study progressed, the accumulation of salts in the filling medium resulted in higher values in the effluents.

Like CE, the average PH values obtained were quite similar between all lines, with little difference between the type of plants and the filling media used. But unlike electrical conductivity, the PH values of the effluents were lower than the values of the AC Affluents

The values of both OD and %OD were initially quite low in module 1. Throughout the study these values increased, and this was due to the degradation of the organic matter of the coconut fibers in the filling media itself and due to the period of adaptation of the plants, leading to a greater consumption of oxygen for the degradation of the respective organic matter and consequently to lower values of DO and %OD.

Comparing the values obtained and represented in table 2 for each line, we can see that in module 1 the plants had a positive impact on the OD and %OD values compared to the line with only filling media, with both species showing relatively values identical. Regarding to module 2, this one presented higher values compared to module 1, we can also verify that the plants (line 4 and 6) had a negative impact on the OD and %OD values compared to the line with only filling media (line 5), which in turn was the line that presented the best results for both parameters.

3.4 Solids

The GW produced and used in this study, presented relatively low values of TSS (total suspended solid). The large percentage of solids present in the produced GW are mostly volatile solids, representing about 75% of suspended solids.

We can see, on table 3, that the solutions which provided greater removal efficiency of TSS were the solutions that combine the filling media of ceramic tiles and coconut fibers and with plants, especially in the case of a line with an Asplenium onopteris (line 3). However, the standard deviation associated with each line presents the value of the order of magnitude of the norms, revealing a high variability of its results.

Table 3 - Results of TSS of each line (average ± standard deviation).

	Nº samples	Min (mg/L)	Max (mg/L)	Average (mg/L)	Standard deviation	% RE
Affluent	19	31	140	72	35	-
Line 1	18	5	120	27	25	61.8
Line 2	18	16	110	44	28	39.1
Line 3	19	5	125	24	28	66.3
Line 4	19	13	73	35	19	51.1
Line 5	19	9	85	32	24	55.4
Line 6	19	17	90	33	18	53.3

In the module with textile fibers filling media, we can observe that the plants didn't had a great impact on TSS reduction, with line 5 (without plants) obtaining removal efficiency values a little higher than the lines with plants and even higher than the line with the ceramic tiles and coconut fibers (line 2).

As it was possible to verify for the reduction of TSS, the lines with filling medium in ceramic tiles and coconut fibers and with plants (line 1 and 3) and the line only with filling media of textile fibers (line 5) were the lines that showed greater removal efficiency of VSS (Table 4). Comparing these three lines, line 3 with the Asplenium onopteris species was once again the line that showed the greatest removal efficiency of suspended solids, reaching an average value of 85.1%. Note that line 5, composed only of textile fibers without any plant, presented values similar to the values obtained in line 1.

Table 4 -Results of VSS of each line (average ± standard deviation).

	Nº samples	Min (mg/L)	Max (mg/L)	Average (mg/L)	Standard deviation	% RE
Affluent	13	25	128	54	31	-
Line 1	13	5	35	19	7	73.6
Line 2	13	15	40	28	8	60.9
Line 3	13	5	20	11	4	85.1
Line 4	13	12	51	25	10	64.6
Line 5	13	7	31	18	7	74.3
Linha 6	13	14	35	24	5	67

In the module with textile fiber filling media (line 4 to 6), the plants had no effect on the reduction of VSS, similarly to TSS, line 5 showed greater efficiency than lines 4 and 6 with plants.

3.5 Chemical oxygen demand

Table 5 presents the statistical results obtained from COD, and it can be observed that the module with filling media of ceramic tiles and coconut fibers had better performance in terms of COD reduction compared to the module with filling media of textile fibers, with and without plants. The line with a felling media composed of ceramic tiles and coconut fibers (line 2) obtained better results compared to all lines of the module with filling media of textile fiber, allowing to conclude that this filling media has a better performance in reducing COD than textile fiber filling media.

Table 5 - Results of CQO of each line (average ± standard deviation).

	Nº samples	**Min (mgO_2/L)**	**Max (mgO_2/L)**	**Average (mgO_2/L)**	**Standard deviation**	**% RE**
Affluent	18	429.1	1016.6	628.7	121.2	-
Line 1	18	130.6	341.2	206.4	52.8	72.7
Line 2	18	170.5	445.8	250.5	71.6	66.8
Line 3	19	116.4	237.6	166.2	34.7	78
Line 4	19	103.1	392	279.7	64.6	63
Line 5	19	158.5	390.8	294.8	67	60.9
Line 6	19	163.7	354.5	264.6	49.4	65

Regarding the influence of plants, we can conclude that the plant of the species Asplenium onopteris (line 3 and 6) was the species that obtained the greatest reduction of COD in both modules compared to the plant of the species Adiantum capillus-veneris (line 1 and 4). In both species there were improvements in terms of COD reduction compared to repetitive lines without filling media of both modules (line 2 and 5).

In general, there was an increase in the efficiency of COD removal throughout the study in all lines, pointing out several factors that contributed to this, among which the degradation of organic matter such as the fibers of coconut and leaves that fall into the green wall modules during the plants' adaptation period, leading to higher oxygen consumption and consequently higher COD values. Another factor that contributed to the increase of COD reduction during the study was the evolution of the bacteriological community over time.

4. Conclusion

To assess the feasibility of green walls for the treatment of GW, it was necessary to analyze several quality parameters. This study also intended to make a comparison between 2 filling media and 2 plant species in order to understand the influence of each one of these and how to obtain a more efficient solution for each of the quality parameters analyzed.

On line 3, with filling media of ceramic tiles and coconut fibers and the plant species Asplenium onopteris, presented the best results for the parameters COD, SST, SST, with removal efficiency values of 73.6%, 66.3% and 85.1% respectively.

As for the OD and %OD, line 5 composed only by filling media of textile fibers was the one that presented the best values, in this case higher values compared to the other lines of the wall, presenting values of 4.93mgO_2/L and 57.2% respectively.

Looking and comparing each filling media, we can see that, in general, the use of textile fibers had a better performance compared to ceramic tiles with coconut fiber, with the exception of COD, in which the textile fibers effectively had a lower performance. Regarding SST and SSV, line 2 presented lower retention values in the initial phase of the study, and at the end of the study its percentage was around 60% for both. We can also conclude that textile fibers alone are a good solution for retaining suspended solids.

As for the plants, as indicated above, the species Asplenium onopteris was the one that showed the best results in both modules. On the wall with filling media of ceramic tiles and coconut fibers, both species had a positive impact. In the case of the wall with a filling media of textile fibers, these did not have a significant impact, and it can be concluded that textile fibers are not the most suitable material for plants, as they absorb a lot of water, getting very soaked and the plants prefer moist soils and airy but not too much.

In general, we can conclude that this study showed very promising results, but that they can still be improved, requiring further studies to achieve the goals regarding the quality of water needed for the various types of use for which it is intended.

4.1 Future work

There were several important parameters to assess water quality that could not be analyzed in this study, but which are just as important as those analyzed, such as microbiological parameters, nitrogen, phosphorus, and others.

There are still several elements to be studied in the future that can bring improvements to this type of systems, such as the effect of the effluent water from the wall re-entering the system, something that certain studies indicate to be beneficial for the final water quality (reference).

This study lasted 2 months during the summer period, and during the first weeks the plants underwent an adaptation period, which conditioned the values obtained during this adaptation period. Studies for longer periods should be carried out to study the long-term effects and how the system itself adapts to the different seasons of the year and respective meteorological conditions, since the plants are sensitive to these, being able to understand how these factors affect or condition the performance of green walls.

Another factor that could be very interesting to study would be the combination of several filling medias in the same flow line, taking the advantages of each solution in the treatment of GW. As indicated above, textile fibers by themselves are a good solution for retaining suspended solids and OD, so it could be interesting, for example, in the same flow line to combine pots with only filling media in textile fibers (in small number due to poor performance in other parameters) improving solids and DO retention capacity, and applying ceramic fibers and coconut fibers with plants in the remaining pots to take advantage of the performance in terms of COD reduction.

5. References

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