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ORIGINAL ARTICLE

Biotechnological approach of greywater treatment and reuse for landscape irrigation in small communities

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UV disinfection

Abstract A level of water quality intended for human consumption does not seem necessary for domestic uses such as irrigation of green spaces. Alternative water supplies like the use of greywater (GW) can thus be considered. However, GW contains pathogenic microorganisms and organic compounds which can cause environmental and health risks. As the risks related to recycling are unknown, GW treatment is necessary before reusing. To describe the risks related to GW reuses, the scientific approach performed in this study was to characterize domestic GW in order to select an appropriate treatment. The biotechnology chosen is a Horizontal sub-surface flow constructed wetland reactor. In order to minimize health risks, an optimization step based on UV disinfection was performed. The treatment performances were then determined. The treated GW produced in this study reached the threshold values expected by the Moroccan regulation for irrigation of green spaces with treated wastewater. Indeed, the COD and the TSS obtained in treated GW without disinfection are respectively 16.6 mg O_2 L^{-1} and 0.40 mg L^{-1}. The horizontal sub-surface flow constructed wetland (HSSF CW) reactor has been used to treat 1.2 m^3/d of GW for 100 days. Three lawn plots have been irrigated respectively with raw GW, treated GW and tap water as a reference. Contrary to the lawn plot irrigated with raw GW, the risk analysis performed in this study has

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shown no significant difference between the law plots irrigated with treated GW combined with UV disinfection and the one irrigated with tap water. Overall, UV disinfection treated GW produced from the HSSF CW reactor developed in this experiment is thought to be an effective and feasible alternative for agricultural reuse.

1. Introduction

Water scarcity is one of the biggest challenges which is faced in arid and semi-arid regions however, is slowly approaching also the mega-cities (Guidelines, 2002; Al-Jayyousi, 2003; Government of Western Australia, 2005; Allen et al., 2010). Greywater (GW) is part of the household wastewaters (Mcllwaine and Redwood, 2010; Al-Mashaqbeh et al., 2012). Accordingly, household wasted water consists of two major components: (i) black wastewater which consists of the toilet wastes that contains faeces, urine and the streams generated by the kitchen sink and the dishwashing machine, and; (ii) greywater wastes that originates from residential clothes washers, bathtubs, showers, bathroom sinks and laundry machines. In Australia the GW (also referred to as sullage) under the regulations, consists of all non-toilet wastewater. Actually, the GW consists of the "dirty water" excluding the kitchen sink and the dish-washing machine. According to the different sources the amount of GW is between 50% and 70% of all the water disposed by every household (regardless of total amount) (Gerba et al., 1995). The main differences of GW from black wastewater are as follows: (i) greywater contains only about a tenth of the nitrogen (ammonia, nitrite and nitrate), since it is the major urine source; (ii) since black water (containing feacal material) is excluded from GW there is a decreased load of feacal pathogenic organisms; (iii) the organic content of GW decomposes more rapidly than black water and assimilation is assisted even further biodegraded when GW is reused by direct application in the root zone. This water, after adequate treatment can be reused close to the house for lawn irrigation mainly, preventing the long-range distance transportation in the expanding mega-cities (Al-Hamaiedeh and Bino, 2010). However, there are several works that recommend the use of GW even for agricultural crops irrigation, still for different water qualities (Finley et al., 2009; Misra et al., 2010; Pinto et al., 2010).

The constructed wetland technology has become useful in mitigating environmental pollution by taking advantage of natural processes for wastewater treatment (Hench et al., 2003; Kivaisi, 2001). Compared to conventional wastewater treatment technologies, constructed wetlands are mechanically simple and have relatively low operation and maintenance (O&M) requirements (Nivala et al., 2012).

According to the flow direction inside the porous medium, horizontal subsurface flow constructed wetlands (HSSFCW) are engineered systems, which mostly employ gravel as substrate to support the growth of plants, and wastewater flows horizontally through the substrate where it comes into contact with microorganisms, living on the surfaces of plant roots and substrate (Kadlec and Wallace, 2009; Knowles et al., 2010).

HSSFCW have been successfully employed to remove classical contaminants from wastewaters, such as the organic load, nutrients (mainly nitrogen and phosphorous) and pathogens (Caselles-Osorio and Garcia, 2006; Akratos and Tsihrintzis, 2007; Vymazal, 2007; Reinoso et al., 2008; Stott et al., 2008; Kadlec, 2009). A large number of physical, chemical and biological processes are involved in these systems influencing each other (Langergraber et al., 2009) such as sedimentation, filtration, precipitation, sorption, plant uptake, and microbial decomposition (García et al., 2010; Kadlec and Wallace, 2009).

In order to protect human health and also the environment, disinfection of treated water for irrigation becomes a necessary part of the treatment, to meet the standard of water quality for irrigation. Ultraviolet irradiation is a physical disinfection process that achieves disinfection by inducing photobiochemical changes within microorganisms. It's a transfer of electromagnetic energy from a UV lamp to organism's genetic material (DNA and RNA). The energy absorbed generate photoproducts such as thymine dimers on the same nucleic acid strand (Harm, 1980), which blocked DNA replication and leading to inactivation of microorganisms If the damage is not repaired (Ko et al., 2005).

That being so, the aim of the current study was to explore the feasibility of a HSSF CW reactor combined with UV disinfection, as it styles itself as a biotechnical sound, low-tech and compatible treatment system with local socio-economic Moroccan context such as an innovative process that would allow safe and sustainable use of GW for landscape irrigation in small communities and households.

Table 1 Design parameters of the HSSFCW system.

Parameters	Amplitude
PE	150
Inflow Rate	1.2 m^3/d
BOD $_{In}$ concentration	50 mg/l
BOD $_{Out}$ concentration	10 mg/l
Daily organic load in (BOD)	60 g/d
Inlet Loading rate in (BOD5)	4.8 g/m^2/d
Area	12.5 m^2
Depth	0.6 m
bottom slope	1%
Plants	*Typha latifolia* (Density of 4 stems/m^2) Age: 2 months
Gravel specifications	Drainage layer: 30 cm on each other Size: 15–25 mm Transition layer: 15 cm on each other Size: 5–15 mm Filter layer: 4.1 m Size: 2–5 mm

2. Materials and methods

2.1. Study area

To achieve the objectives of this research, an HSSFCW was built at a Primary school in Marrakech (Morocco) (31° 42′ 24″ N, 7° 58′ 50″ W, 451 m), with an average annual temperature of 19.6 °C and annual precipitation of 282 mm. At the upstream, all the school grey water was collected from hand wash sinks and directed to a pre-treatment unit. The pre-treatment consisted of coarse screening, and then the grey water was conveyed to a HSSFCW whose sizing parameters are summarized in Table 1.At the downstream end of the reactor a disinfection process was set up to minimize health risk (Fig. 1).

2.2. .Design of the HSSFCW

The design was established according to old kinetic removal models (the *K-C** model) based on the plug flow model which was developed and synthesized by Kadlec and Knight (1996). The empirical formula used is given by the Kickuth (1977).

2.3. Tertiary treatment (UV-minireactor)

Treated effluent was then disinfected using a minireactor of 8-lamps (50 W each) low-pressure UV irradiation closed system. The UV reactor is an open-channel system with two UV banks; each consisting of four low pressure high intensity UV lamps that produce essentially monochromatic UV light at 253.7 nm. Dose adjustments were made by changing the incoming flow rate and altering the number of banks in operation, to meet an operating UV dose of 50 mWs/cm^2. Using sterile bottles samples were taken from the upstream and downstream of UV minireactor and transported to the laboratory for analysis immediately after collection.

Disinfected effluent was stored in a tank (10 m^3), whose water was used for irrigation. Stored water was pumped to the experimental site for irrigation. This operation is regulated by a control unit which regulates valves opening of irrigation plant.

Disinfection section was previously optimized for UV during a trial period before the start of the irrigation test.

2.4. Sampling and analysis

For the qualitative determination of Physico-chemical and Microbiological parameters of greywater produced by the schoolboys and the treated greywater, a water quality monitoring was provided over a period of 100 days at the inlet and at the outlet of the HSSFCW, with a variable hydraulic loading rate of 0.4–1 m^3/d). The sampling campaign started on April 20, 2013 and ended on July 30, 2013 with a frequency of:

- Once every five days for the Physico-chemical parameters; pH, EC, BOD5, COD, TSS, TN, TP (number of samples = 20)
- Once in a fortnight for the Microbiological Parameters; FC (number of samples = 7)

Samples were stored inside dark glass bottles, and placed in a fridge-box (at 4 °C) till their arrival the same day at the laboratory. Usually, samples were collected in the morning and the laboratory analyses started in the afternoon.pH, dissolved oxygen, electrical conductivity and temperature were measured in situ using a multiparameter probe type WTW multi 340i/set (WTW Büro–weilheim, Germany). The other physico-chemical parameters were measured according to French standard methods (AFNOR, 1997) and (Rodier, 1996). Biological oxygen demand (BOD5) was determined by the modified Winkler method, total chemical oxygen demand (COD) and dissolved chemical oxygen demand (Dissolved COD) were analysed according to the dichromate open reflux method (APHA, 1992). Suspended solid (SS) concentration was determined by the filtration method, Anionic surfactant concentration using the ISO 78-75-1standart, NH_4^+-N concentration by the indophenol method, NO_2-N concentration by the diazotization method, PO_4^--P concentration by the ascorbic acid method and total phosphorus (TP) were determined as PO-4-P after potassium peroxodisulfate digestion (AFNOR, 1997). NO_3^--N was analysed as NO_2^--N after their reduction through a cadmium-copper column according to the (Rodier, 1996). Total Kjeldahl nitrogen (TKN-N) was determined by Kjeldahl mineralization and distillation of ammonium and a final acidimetric titration and total nitrogen (TN) was the summation of NH_4^+-N, NO_2^--N, NO_3^--N and TKN-N.

Bacteriological analysis has focused on *Escherichia coli*, Enterococci, total coliforms, mesophilic flora, Legionella, *Pseudomonas aeruginos*a, *salmonella* sp. and *staphylococci*. The analysis was performed according to the dilution method or the most probable number (MPN) technique for the samples suspected to be highly contaminated (Moroccan Standards, 2006). The removal of the microbiological indicators was expressed as (CFU/100 mL) and (NPP/100 ml).

The regulation fixed the monitoring of five parameters (SM, COD, faecal entrocoques, RNA phages F-specific, spores

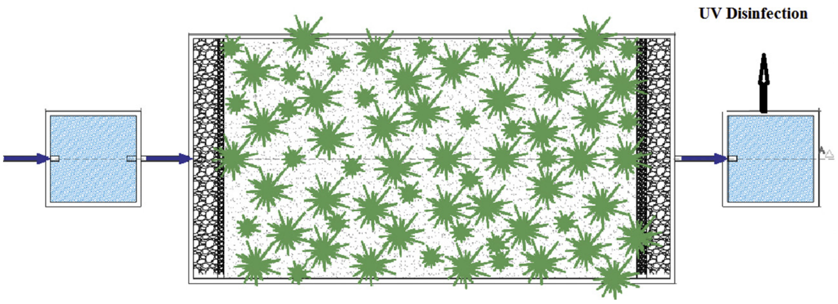

Figure 1 The HSSFCW layout.

Table 2 Properties of raw greywater and those found in the literature.

Parameter	Unity	Greywater of this study			Literature[*]	
		Mean	Minimum	Maximum	Minimum	Maximum
PH	–	7.6	6.7	8.0	5	10
EC	µS/cm	580	501	789	82	627
Turbidity	NTU	65	41	109	5	462
SS	mg/l	5	2.1	8.1	7	361
COD	mgO$_2$/l	77.2	11	112	39	1815
BOD5	mgO$_2$/l	44.2	13	65	26	670
Anionic surfactants (mg SABM/L)	mgSABM/l	4	2	7	0.3	16
TN (mg N/L)	mgN/l	7.1	4	11	0.6	40
TP (mg P/L)	mgP/l	0.8	0.1	3	0.1	101
Escherichia coli	NPP/100 ml		2.10^1	3.10^3	0	2.10^6
Total coliforms	UFC/ml		4.10^1	5.10^5	3.10^2	2.10^7
Mesophilic flora (37°)	UFC/ml		1.10^2	4.10^4	5.10^6 (UFC/100 ml)	5.10^9 (UFC/100 ml)

[*] (Chaillou et al., 2010; Christova-Boal et al., 1996; Donner et al., 2010; Gross et al., 2007; Hernández et al., 2007; March et al., 2004; O'Toole et al., 2012; Rodda et al., 2011).

Table 3 Concentrations of physico-chemical and microbiological parameters at the inlet and outlet of the HSSF and removal efficiency percentage.

Parameters	Raw grey water	Treated greywater	(%) Removal
pH	7.6	7.8	
EC (µs/cm)	580	540	
Turbidity (NTU)	65	8	88
SS (mg O$_2$/l)	8	0.8	90
COD (mg O$_2$/l)	77.2	8.5	89
BOD5 (mg O$_2$/l)	44.2	5.74	87
Anionic surfactants (mg SABM/L)	4	0.64	84
TN (mg N/L)	7.1	4.12	42
TP (mg P/L)	0.8	0.4	50

of anaerobic bacteria and *E. coli*), in order to use the treated greywater (GW) for irrigation green spaces of school. These parameters have therefore been analysed because they are the only regulatory parameters. In addition, this decree recommends following turbidity, dissolved organic carbon (DOC), the biological demand of oxygen for 5 days (BOD5), total phosphorus (total P), nitrogen compounds and Legionella and amoeba. Finally, to complete the study, pH, conductivity, surfactant concentration, mesophilic flora, total coliforms, *P. aeruginosa*, pathogenic *staphylococci*, *Clostridium perfringens* SAR and salmonella sp. were also analysed.

3. Results and discussion

3.1. Quality of raw GW in reactor inlet

Table 2 shows the physico-chemical and microbiological quality of raw GW produced and those found in the literature .The results presented in this table show a disparity in the composition of raw GW, whether in literature or in the present study. The parameters such as turbidity or TSS show variations up to 82% between the minimum and maximum value. These variations are due to customs of uses (Eriksson et al., 2002) and depend on the type of laundry, shower gel or shampooing used, this variations can lead to disturbances during processing.

If the produced raw GW in this study differs widely from one sample to another, it is nevertheless comparable to those found in the literature.

Microbiological results show that, only total coliform, mesophilic flora and *E. coli* were observed. The other microorganisms such as *Legionella* (and *pneumophila* spp.), spores of sulphite-reducing anaerobes, *Pseudomonas aeruginosa*, pathogenic staphylococci, *salmonella* sp., *C. perfringens* SAR and F-specific RNA phages are below the detection limit in the raw GW.

In literature, few studies have examined; just one or two microbiological parameters as contamination indicators, but none includes all the parameters previously cited. In addition to that, very few studies have properly addressed the possibility to highlight the combination of HSSFCW with UV disinfection as a unit of greywater treatment process.

There is great variability in the concentrations of indicator bacteria reported in the literature for different grey water streams and between different studies examining similar grey water streams. Organic matter seems to have been the primary parameter of concern regarding grey water reuse in the literature so far. However bacteriological parameters in grey water are comparable to those in conventional domestic wastewater. A comparison of those indicators with standards and guidelines used for grey water reuse indicates that these parameters should not be overlooked. This point at the necessity to consider microbiological indicators as parameters of prime importance when it comes of public health.

3.2. Performance and treatment of reactor

3.2.1. Physical and chemical characteristics

The greywater in and out of the HSSFCW reactor was characterized to study treatment performance.

Table 3 shows the physicochemical characteristics of the GW and the abatement for each of the parameters. However,

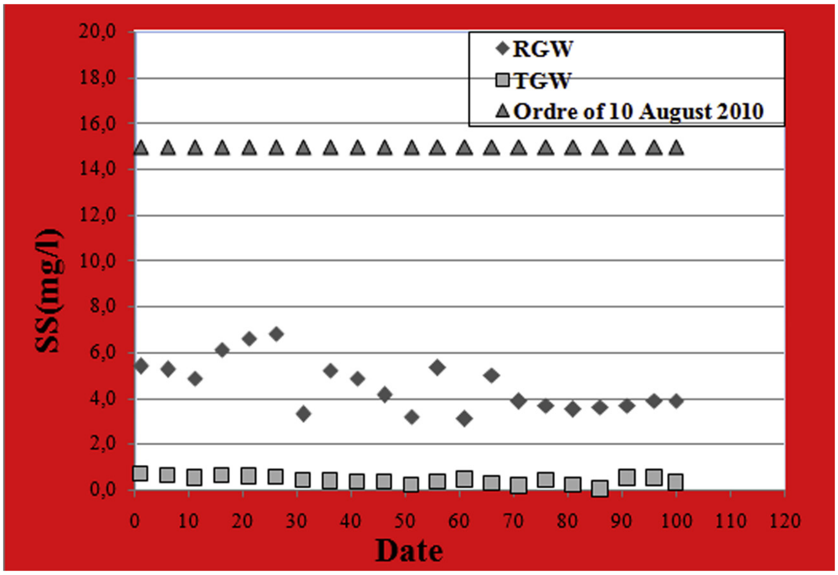

Figure 2 Chemical oxygen demand contained in the RGW and TGW.

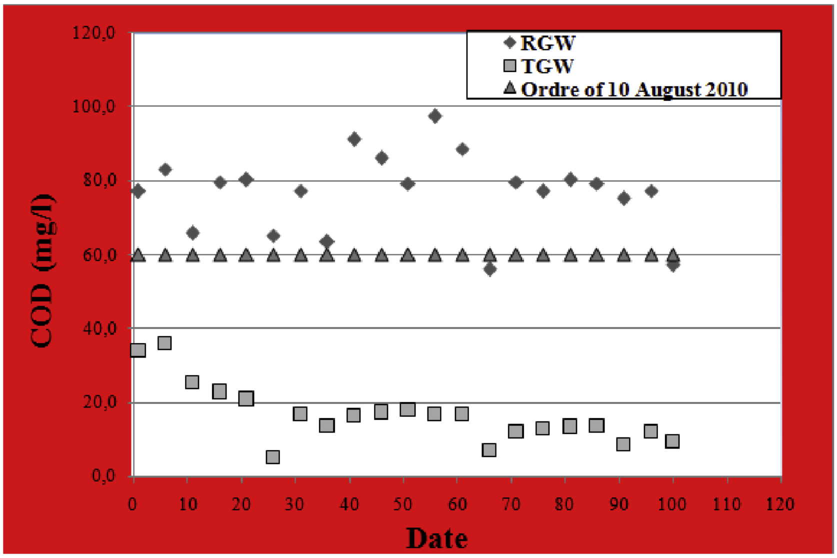

Figure 3 Suspended solids contained in the RGW and TGW.

if the inlet changes of reactor are high, processing performances are stable.

Indeed, there were no overruns of the limits of SS and COD, respectively set at 15 mg/l and 60 mg O_2/l (Figs. 2 and 3) .The process has allowed achieving 88% of abatement for COD and SS, only physicochemical parameters for which the regulation sets a value.

Regarding other parameters, the treatment achieves respectively 88, 87 and 84% for turbidity, BOD 5, and surfactants. This abatement is satisfactory and consistent with what can be found in the literature (Baban et al., 2010; Hernández et al., 2010; Lamine et al., 2007; Pathan et al., 2011). The low abatements of nitrogen and phosphorus can explain by their low concentrations entrance to the process. In addition, to the use of treated GW for irrigation of green areas, nitrogen and phosphorus can be used as nutrients and promote growth. They can therefore be considered as a positive contribution to the reuse of GW.

3.2.2. Microbiological characteristics

Table 4 shows the characteristics of some microbiological parameters studied that showing results in GW. The other microorganisms are not detected.

Table 4 shows that many microorganisms are present in the WG at the input and output of process .The variations are between 1 and 3 unit log, which exceed the standard water for irrigation. Therefore it is proposed to add a UV disinfection step after the reactor to reduce the intake of microorganisms to treated GW. That was made in this study by combined a minireactor of UV disinfection and the obtained results are presented in Table 5 below.

Table 4 Microbiological properties of greywater in inlet and outlet of the bioreactor before disinfection.

Location		Inlet		Outlet	
Value		Minimum	Maximum	Minimum	Maximum
Escherichia coli	NPP/100 ml	2.10^{2}	3.10^{4}	2.10^{1}	2.10^{3}
Total coliforms	UFC/100 ml	4.10^{1}	5.10^{5}	2.10^{1}	3.10^{3}
Mesophilic flora (37°)	UFC/100 ml	$1,5.10^{2}$	4.10^{5}	1.10^{2}	$2,6.10^{4}$

Table 5 Microbiological properties of greywater in inlet and outlet of the bioreactor after disinfection.

Location		Outlet of HSSF CW reactor		Outlet of UV minireactor	
Value		Minimum	Maximum	Minimum	Maximum
Escherichia coli	NPP/100 ml	$2,5.10^{1}$	2.10^{3}	2	7
Total coliforms	UFC/100 ml	2.10^{1}	3.10^{3}	4	1.10^{1}
Mesophilic flora (37°)	UFC/100 ml	1.10^{2}	$2,6.10^{4}$	5	9

Table 6 Properties of the percolates from irrigated parcel.

Parcel	Raw GW			Treated GW			Drinking water		
Value	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
PH	7.9	7.6	8.3	7.9	7.6	8.3	7.9	7.6	8.3
EC	750	520	960	647	545	912	532	501	836
Turbidity	17	13	26	14	12	19	7	5	9
SS	<1.5	<1.5	8	<1.5	<1.5	6	<1.5	<1.5	<1.5
COD	150	78	230	111	97	123	55	42	63
BOD5	21	7	28	12	2	26	7	1	13
Anionic surfactants (mg SABM/L)	0.95	0.37	2	0.46	0.15	1.02	0.32	0.11	0.85
TN (mg N/L)	2.5	1.0	5.1	1.8	1.5	3	1.6	0.9	3
TP (mgP/L)	0.7	<0.5	0.9	0.7	0.7	0.9	<0.5	<0.5	<0.5
Enterococci	–	10	20	–	10	55	–	12	45
Escherichia coli	–	2.10^{1}	2.10^{2}	–	3.10^{1}	4.10^{1}	–	20	1.10^{2}
Total coliforms	–	< LD	1.10^{2}	–	< LD	5.10^{2}	–	< LD	3.10^{5}
Mesophilic flora (37°)	–	2.10^{2}	3.10^{4}	–	8.10^{2}	6.10^{4}	–	5.10^{2}	3.10^{4}

The UV potential applied in the minireactor providing up to 4 unit log inactivation for mesophilic flora (37°) and 3 unit log inactivation for *E. coli* and total coliform. The results show also that, the UV minireactor designed in this study with a UV dose of 50 mWs/cm^{2} is adequate to comply with the unrestricted irrigation conditions of WHO and Moroccan Guidelines, which limits the foecal coliform content to 10^{3} FC/100 ml (Blumenthal et al., 2000). On the other hand, it is adequate to comply with the California water recycling criteria for disinfected secondary-23 category of reclaimed waters, which is one of the most stringent guidelines for irrigation waters that limits the foecal coliform content to 23 FC/100 ml (Tchobanoglous et al., 2003a,b).

3.3. Quality of the percolates from parcel

The percolates from irrigated plots were analysed when enough could be harvested. Since the beginning of the irrigation four samples were analysed. The results are shown in Table 6.

For Physicochemical parameters, with the exception of conductivity and COD, the quality of the percolates is pretty similar. However, the conductivity of percolate from the irrigated plot by raw GW seems superior. This trend decreases with time, and the conductivity of the last samples is similar to that of other leachates.

Regarding the COD, the observed difference can be explained by the accumulation of organic matters presented in GW, but also the natural environment (grass, soil and fauna). Indeed, in the raw GW or processed, no enterococcus was then observed even they could be detected in the percolates in each plot, even those irrigated with potable water. The compositions of the percolates in each plot being close, the quality of irrigation water has little influence on the quality of the percolate. Thus, irrigation of green spaces with treated GW seems a promising way to reduce the demand for potable water.

Table 7 Collected biomass in terms of type of used water for irrigation.

Type of water used for irrigation	Dry biomass (g)	Additional biomass in relation to the parcel drinking water
Raw greywater	181	126
Treated Greywater	189	132
Drinking water	105	–

3.4. Harvested biomass

After 40 days of irrigation, the entire lawn of each plot was harvested. Height was performed manually and the harvested biomass was dried, and weighed. Preliminary results are reported in Table 7.

First, the amount of biomass harvested for irrigated plots by raw GW and treated is identical. The observed difference of less than 4% is probably caused by harvesting way of the lawn. However, the amount of plant biomass produced by irrigated plots by GW is higher than irrigated by the potable water. Thus the production of additional plant biomass is 160% for both plots. This difference may be due to the presence of nutrients in the GW which is a supply to the lawn and promotes growth.

A second positive aspect of the GW reuse for irrigation of green spaces is the supply of nutrients for plant development. This observation is the result of a single crop, it will be necessary to confirm later at the next mowing.

4. Conclusion

This study measured the physicochemical and microbiological characteristics of raw GW produced from washbasins school. These last were processed through a reactor HSSFCW and used for irrigation of lawn plots.

The treatment process performance and environmental impact GW reuse were able to be studied. The quality of raw GW has produced wide variations, either at the physicochemical or microbiological parameters. However, the reactor used for the process has achieved the physicochemical quality as required by the regulation.

In addition, the quality of treated GW presents a little change, that showing the reliability and the robustness of the process. Irrigated lawns with different types of water seem to grow properly. And those irrigated by GW seem to grow more quickly, due to the richness of this water by nutrients. Concerning the disinfection, the experimental results obtained in this study showed that 50 mWs/cm^2 UV dose is more enough to meet the microbial quality standards for water irrigation.

The use of treated GW for irrigation of green spaces thus has two main advantages. It reduces the consumption of drinking water and does not disturb the growth of plants.

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