Sustainability indicators of subsurface flow constructed wetlands in Portuguese small communities

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Abstract: - The discharge of untreated domestic wastewater in the receiving waters creates a negative and environmental impact, inversely proportional to its autodepuration ability.
Conventional wastewater treatment plants involve large capital investments and operating costs, and could be economically unsustainable for small-medium communities. So, constructed wetlands as natural low-cost systems can be an appropriate alternative, because they require low maintenance, give rise to good performances and provide a natural appearance.
This work presents a synthesis of data obtained through an extensive survey performed in twenty Portuguese constructed wetlands utilities. Based on this information, some sustainable indicators and removal pollutant efficiencies were calculated. Besides identifying the main operational problems observed, it was also possible to detect inadequate monitoring procedures, aiming, with some proposed corrections, to improve the performance of these low-cost wastewater treatment utilities. The results obtained in this work encourage the development of future studies to increase the performance of these wastewater systems based on a better knowledge of the influence of hydraulic parameters, like flow, retention time and hydraulic application rate, in the pollutants removal efficiencies.

Key-Words: - wastewater treatment; natural systems; constructed wetlands; monitoring, sustainability indicators, performance evaluation.

1 Introduction

Natural systems for municipal wastewater treatment, like constructed wetlands (CWs), have been set up all over the world over the last few decades as a good and sustainable alternative to conventional systems for the sanitation of small-medium communities.

For communities with less than 2000 inhabitants, it appears that the solutions of biological conventional wastewaters treatment (like activated sludge or trickling filters) have high costs or low efficiencies (like collective septic tanks) that render the fulfillment of more exigent requirements. This has attracted a growing interest for the development and application of low-cost technologies to ensure the sustainability of small wastewater treatment plants (WWTPs).

Most of constructed wetlands present a low cost (installation and maintenance), lower energy requirements and technical skills of operators, good efficiencies, environment friendly landscape, and reduced production of sludge.

So, constructed wetlands are gaining importance as an effective and low-cost technology for the treatment of septic effluents in small villages [1].

When the sustainability of the wastewater treatment from a large number of rural villages is an imperative, the performance evaluation of the constructed wetlands systems operating in Portugal, is real need. Indeed, it is crucial to validate them as a credible alternative to conventional methods of wastewater treatment.

The performance evaluation of these systems must considerer not only the protection of the user´s interests (accessibility and quality of service), but also the assessment of utility´ sustainability, considering economic, financial, infrastructural, operational and human resources aspects [2].

Environmental sustainability must be linked with an integrated water resources protection policy, in order to mitigate discharges impact effects in receiving waters. Excessive nutrients inputs can lead to the eutrophication of the aquatic ecosystems, which is widely recognized as a major worldwide threat [3]. So, utilization efficiency of energy resources, wastewater quality control, and compliance with parameters discharge standards and final disposal of produced sludge must also be assessed [4].

Concerning with this sustainability criteria, CWs presents certain advantages over the conventional treatment systems: they can be established in the same place as where the waste water is produced; they can be maintained by relatively untrained personnel; they have relatively lower-energy requirements and the obtained biomass could be utilized as fuel in a small boiler for domestic uses.

Wetland ecosystems have special characteristics which make them particularly suitable for wastewater treatment: they are semi-aquatic systems which normally contain large quantities of water; they have oxic and partly anoxic soils in which the organic matter biodegradation takes place; and they support a highly productive, tall emergent vegetation capable of taking up large amounts of nutrients and responding to enrichment with nutrients with enhanced growth [5].

The worst problem usually observed in CW systems is the progressive clogging that occurs near the inlet, which is a result of solids entrapment and sedimentation, biofilms growth, and chemical precipitation. All of these processes promote the occlusion of interstitial spaces, which leads to a decrease in the hydraulic conductivity and effective volume, and an increase in the water velocity. One possible way to reduce the clogging rate of an SSF CW is to use intensive preliminary processes such as coagulation and flocculation followed by clarification, membrane filtration and primary effluent filtration [6].

CWs are usually utilized as secondary treatment [7] requiring, in such systems, a physical pre-treatment, like a primary filtration of coarse material, in order to keep the system functioning well. But, the use of a physic-chemical treatment as a preliminary step for SSF CWs did not clearly improve the quality of the effluents in terms of turbidity, COD and ammonia, at least during the initial months of operation [8]. These authors concluded that COD removal efficiency was not dependent on the tested hydraulic retention time (HRT), ranging from 2 to 6 days, whereas ammonia concentration removal clearly decreased for lower HRT.

If a wastewater tertiary treatment is needed, it will render the CW system as an unrealistic alternative [1], and an appropriate post-treatment must be adopted [9], considering the receiving waters sensibility or reuse requirements. There are also quite a few cases in which a wetland is being used for polishing the effluent of a conventional purification plant

If CWs are only used for primary treatment, (absence of others complementary treatment unities), toxic effects on the aquatic plants due to the high organic loading of the influents has been reported [10].

Subsurface flow (SSF) constructed wetlands (CW) consist of four main components: water, soil, plants and microorganisms and there is a close relationship between them [11]. The removal of any pollutant depends on these four components and involves many mechanisms [12].

In most of Mediterranean countries as well as in Portugal there are no specific regulations and design criteria of CWs for wastewater treatment. So, there is a great need to establish regulations suitable for warm climate conditions. [13]. Advantages of CWs application in Portuguese rural communities are unquestionable, because temperature and land availability and costs are not the limiting factors.

The majority of constructed wetlands in Portugal used for the biological treatment of municipal sewage are designed as horizontal subsurface flow (HSSF) systems [14, 15]. At this time, very little data concerning Portuguese CWs performance evaluation had been reported avoiding to confirm its capacity and effectiveness on COD, BOD5, total suspended solids (TSS) and ammonia removal. Data obtained in Spain showed that the average load applied to HF-CW is higher than in other ones cited in the literature and proved that those systems perform very high organic matter removal comparing to the other European countries [16]. This performance could also be achieved in Portuguese CWs due to its close localization, similar climate conditions, regulations and design criteria. However, more data must be provided in order to validate this conclusion and to establish accurate guidelines for design, management and monitoring procedures, aiming the sustainability of those wastewater treatment facilities.

The main objective of this work is to contribute to increase the knowledge about the Portuguese constructed wetlands characteristics and performance, in order to validate it as a credible and suitable alternative for wastewater treatment in rural areas [17].

This work presents a characterization of twenty constructed wetlands, an analysis of unit costs of treatment and the unit areas, and proceeds to the evaluation of their efficiency on the main wastewaters quality parameters. Based on this information, some sustainable indicators and removal pollutant efficiencies were calculated.

Moreover, the analysis identifies the major operational problems of these systems, suggesting a few mitigating measures and/or corrective to both the improvement of its operation, and the streamlining of its procedures for an accurate monitoring.

2 Methods

2.1 Constructed wetlands composition

The constructed wetlands can have various forms or configurations, depending on the need to adapt to the morphology of the land, but usually have rectangular form.

In general, the wastewater facilities using constructed wetlands are also composed by several unit processes performing preliminary, primary and secondary (biological) treatments. The preliminary treatment is generally composed of a grid to remove the larger suspended solids. The primary treatment is provided by a settling and flotation tank (*Imhof* tank or septic tank), with efficiencies from 30 to 50% in TSS removal and near 20% in DBO removal, including oil and fats. This body, and reduce, by simple processes of separation, the concentration of some pollutants and contaminants to avoid clogging the sub-surface of the bed, thereby increasing its operation period [18].

The biological treatment is provided by one or more macrophytes beds (MB) (Fig. 1). The media bed is essential for plants (macrophytes) anchorage and biofilms (aerobic and anaerobic bacteria) development, which is crucial to performs the biodegradation of organic matter.

Fig.1 Macrophytes beds construction

The continuous growth of roots, adsorption, sedimentation and precipitation of wastewater compounds and, also, the biofilms release over operation time leads to the development of clogging, worsening the solute distribution and the overall performance of the system.

The filling of the bed consists of several layers with different size and height, to minimize the risk of clogging [19]. The bed is usually sealed at the bottom and slopes with a screen of polyethylene to prevent contamination of groundwater and to allow that macrophytes are continuously fed with organic matter. To prevent the rapid clogging of the granular medium, USEPA [20] recommends an organic load lower than 6 g BOD/ m^2/d for HSSF CWs and lower than 25 g BOD/m^2/d for VSSF CWs.

Several species of macrophytes have been used for domestic wastewater treatment, but the most frequent are *Typhas*, *Phragmites*, *Juncus*, *Scirpus* and *Iris* (Fig. 2). These plants are adapted to live in waters with high organic load and, through photosynthesis, send oxygen to the roots promoting the degradation of organic matter.

Camacho *et al.* [12] have compared the effect of four different plant species ─ *Phragmites australis*, *Lythrum salicaria*, *Cladium mariscus* and *Iris pseudacorus* ─ on the operating conditions and their efficiency on pollutants removal. They concluded that *Lythrum salicaria* and *Iris pseudacorus*, which exhibited greater growth, were always the most efficient species that improved not only nutrients plant uptake but also other microbial removal processes probably due to a higher aeration potential, such as nitrification or aerobic respiration.

Cladium mariscus, an autochthonous plant that grows in the south-central Iberian Peninsula, was less efficient than *Lythrum salicaria* and *Iris pseudacorus*. but improved the unplanted wetland wastewater efficiency.

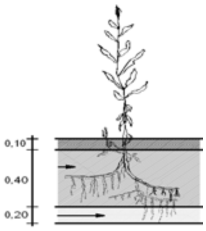
Family: *Iridaceae*
Specie: *Irís Pseudacoru*

Family: *Juncaceae*
Specie: *Juncus effusus*

Family: *Gramineae*
Specie: *Phragmites australis*

Family*: Cyperaceae*
Specie: *Schoenoplectus lacustris:*

Family: *Typhaceae*
Specie: *Typha latifolia*



Schematic bed composition

Fig.2 Major species of macrophytes used for domestic wastewater treatment

2.2 Classification of constructed wetlands

The classification of constructed wetlands is based on the specie of plant used (floating, submerged or emerging). For the other hand, the emerging bed plants can also be classified according to the type of flow (surface or sub-surface).

The beds with sub-surface flow may be classified according to the direction of flow: horizontal, vertical, or hybrid [21].

In a rhizospheric system (Fig. 3), corresponding to an aquatic macrophytes emerging system with a sub-surface flow, wastewater is distributed into the bed over the area of roots and rhizomes.

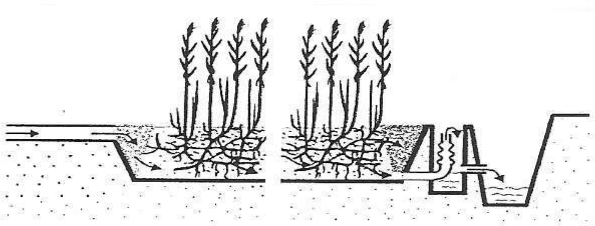


Fig.3 Rhizospheric system scheme

During its percolation several physical, chemical and biological processes contribute to a good depurative performance, achieving, in most cases, the legal limits for wastewater discharge stated in the European emission standards.

The constructed wetlands with sub-surface flow derive advantage of percolation through a stratified medium, where the mechanism of biological filtration shows higher rates of removal of pollutants and contaminants when compared to surface flow systems, thereby requiring a smaller area of occupation. Moreover, the fact that the water level is below the surface, besides being an aesthetic advantage of the bed, favors the stability of biochemical reactions in the lower layers, even in cooler climates, due to the action of the soil as insulating heat.

2.3 Constructed wetlands design methods and operating conditions

All of the most widespread CW design methods, except the EPA method [19], calculate the surface area of the beds as a function of the organic matter decay based on a first order kinetic equation.

The difference found in the several CW design methods searched lies in the values used for the kinetic constant and in its variation with temperature of the medium. Despite its specificity (areas of operation to separate), the model proposed by the EPA based on the size of the beds, has the basic elements common to other methods, including flow rate, the concentrations of the most relevant parameters (BOD5, COD, TSS, N or P) and the removal rates required for this parameters.

Operating conditions of a CW for an affective area can be described by the range of values observed for the several major hydraulic and quality parameters: flow rate; hydraulic loading; hydraulic retention time; BOD5, COD and TSS influent concentrations; and organic matter loading.

In general, it can be said that the biological processes provide elements to calculate the surface area of the bed, the characteristics of the used macrophytes determine the bed' depth and hydraulic parameters (flow rate, hydraulic retention time, and head loss) determine the volume and the configuration of each macrophytes bed.

2.4 Portuguese constructed wetlands survey

The need to select appropriate and sustainable solutions for a large number of rural Portuguese villages, where WWTPs must be designed and built (in a short term), became relevant to evaluate the performance of the existing constructed wetlands and the identification of its major operational problems.

With this goal, twenty HSSF CW systems were selected to study their characteristics and operations conditions, across almost all the country. The survey was intended to be as comprehensive as possible through consultation with experts and utilities' managers, and to guarantee the representativeness of the sample, considering different climatic zones, cultural habits, type of settlement and economic activities.

Wastewater treatment facilities selected are operating since late 90s, and were designed for a served population between 109 and 1160 persons equivalent (PE). Most systems have a septic tank as the primary treatment.

Table 1 presents a summary of the information obtained through on-site visits, namely the type of system, surface, years in service, efficiency, costs, flow rate, type of macrophytes, operational problems, type of media, influent and effluent contaminant concentrations, plant configuration and primary treatment. Furthermore, a questionnaire was send to the administrations also asked for the main physic-chemical parameters analyzed at each facility.

Table 1 - Summary of the characterization of Portuguese CW systems surveyed

WWTP Name	Year	P.E.	Surface (m^2)	Surface of beds (m^2)	Macrophyte specie	Beds	Cost (€)	Frequency analysis	Maintenance	Problems
Alcochete	2001	500	4000	1764	*Phragmites*	4	189500	Semester	Yes	No
Aranhas	2004	437	4100	836	*Phragmites*	1	-	Monthly	Yes	Clogging, Solids
Arganil	2002	109	800	160	*Juncus*	1	41000	Annual	No	Clogging, Solids
Carregal do Sal	1998	200	655	338	*Phragmites*	2	-	Quarterly	Yes	Clogging
Condeixa	2002	600	4600	1600	*Íris, Typha*	1	144500	Quarterly	Yes	Clogging
Covilhã	1999	840	2398	1045	*Typha*	1	99760	-	No	Clogging, Solids
Grândola	2000	500	1100	500	*Phragmites*	1	82182	-	No	Clogging
Guarda	1999	1160	2500	2500	*Phragmites*	2	130000	Monthly	Yes	Clogging, Odors
Madeira	2003	200	541	441	*Phragmites, Íris, juncus*	3	130000	Monthly	Yes	No
Mealhada	2000	125	1000	350	*Phragmites*	1	38513	Monthly	Yes	Clogging
Odemira	2001	350	1360	714	*Phragmites*	2	87040	Annual	Yes	No
Penacova	2001	500	3240	1860	*Phragmites*	2	97266	Quarterly	Yes	Clogging
Rossas	2001	600	1800	1444	*Phragmites*	4	100802	Monthly	Yes	No
Salamonde 1	1999	250	700	289	*Phragmites*	2	64750	Monthly	Yes	No
Salamonde 2	2001	250	600	289	*Phragmites*	2	-	Monthly	Yes	No
Salvador	2004	563	3100	630	*Phragmites*	2	-	Monthly	Yes	Clogging, Solids
St.Comba Dão	1999	300	1153	585	*Typha*	1	31159	Annual	No	Clogging, Solids, Odors
Tondela 1	1997	200	686	656	*Juncus*	1	-	Annual	No	Clogging
Tondela 2	1998	200	562	532	*Juncus*	1	-	Annual	Yes	Clogging
Vila de Rei	2000	1054	4325	855	*Phragmites*	1	185000	Quarterly	Yes	Clogging, Odors

The most used macrophyte is the common read (*Phragmites australis*) which was applied in 70% of the CW systems surveyed. Similar percentage was found for the systems serving populations less (or equal) than 500 PE.

It appears that only part of these systems (75%) has been carried out regular monitoring of the major wastewater quality parameters (BOD5, COD, TSS, P and N), before and after treatment procedure. Some wastewater utilities only control the emission values (in the effluent) to assess its compliance with discharge legal limits and only 75% do this control once a year.

Moreover, not all WWTP managers provided other relevant information requested, like the cost of the system, the design criteria adopted, and the maintenance tasks usually performed.

2.5 Sustainability indicators

A sanitation system and its services provided only can be considered as *sustainable* if they protect and promote human health, do not contribute to environmental degradation or depletion of the resource base, and are technically and institutionally appropriate, economically viable and socially acceptable. Inadequate focus on sustainability of services (O&M, clear division of responsibility between household and service provider) may render any sanitation technology, however well designed and environmentally sustainable, a health hazard. [22].

Implementing sustainability means seeking solutions that balance the costs with respect to the different resources in such a way that the contribution to local and global problems is minimized [23].

In this work, and considering the available data provided by the performed survey, we have selected the sustainable indicators presented in Table 2, based on their relevance to wastewater treatment performance evaluation and its capacity for sustainability (or not), considering economic, environmental, and social issues.

Table 2 – Selected sustainability indicators

Indicator		Unit
ECONOMIC	Unit cost of construction (per WWTP surface)	€ m^{-2}
	Unit cost of construction (per MB surface)	€ m^{-2}
	Unit cost of construction (per inhabitant)	€ $PE^{-1.}$
ENVIRONMENTAL	BOD5	% (efficiency)
	COD	% (efficiency)
	TSS	% (efficiency)
	TN	% (efficiency)
	TP	% (efficiency)
SOCIAL	Specific WWTP surface	m^2 PE^{-1}
	Specific MB surface	m^2 PE^{-1}
	Aesthetic issues	Landscape, odors

3 Results

Based on the characterization of the constructed wetlands surveyed, it was performed a data analysis in order to calculate sustainable indicators values, related to investment costs, pollutant removal efficiencies, and surfaces occupied by the various systems and their macrophytes beds. These indicators allow a better comparison between the different surveyed CW and with others similar works developed in the Iberian countries [16, 24].

3.1 Economic and social indicators

Table 3 presents a summary of the reference values obtained for the selected economic and social sustainability indicators, and the analysis of the indicators variability considering two different ranges of PE value.

Table 3 – Economic and social indicators

WWTP	PE	Unit costs of construction			Specific surfaces	
		System	MB	PE	System	MB
		€ m^{-2}	€ m^{-2}	€ PE^{-1}	m^2 PE^{-1}	m^2 PE^{-1}
Alcochete	500	47	107	379	8.0	3.5
Aranhas	437				9.4	1.9
Arganil	109	51	256	376	7.3	1.5
Carregal do Sal	200				3.3	1.7
Condeixa	600	37	90	285	7.7	2.7
Covilhã	840	41	95	119	2.9	1.2
Grândola	500	75	164	164	2.2	1.0
Guarda	1160	52	52	43	2.2	2.2
Madeira island	200	294	442	650	2.7	1.5
Mealhada	125	39	110	308	8.0	2.8
Odemira	350	64	121	249	3.9	2.0
Penacova	600	30	52	162	5.4	3.1
Rossas	600	56	70	168	3.0	2.4
Salamonde 1	250	72	224	259	2.8	1.2
Salamonde 2	250				2.4	1.2
Salvador	563				5.5	1.1
St. Comba Dão	300	27	53	103	3.8	2.0
Tondela 1	200				3.4	3.3
Tondela 2	200				2.8	2.7
Vila de Rei	1054	43	216	176	4.1	0.8
Average	**452**	**66**	**147**	**246**	**4.5**	**2.0**
Standard deviation	291	65	104	148	2.2	0.8
Correspondent values considering only the CWs with **PE ≤ 500**						
Average	**279**	**84**	**185**	**311**	**4.6**	**2.0**
Standard deviation	131	87	123	167	2.6	0.8
Correspondent values considering only the CWs with **PE > 500**						
Average	**774**	**43**	**96**	**159**	**4.4**	**1.9**
Standard deviation	247	10	62	79	1.9	0.9

The average unit cost of construction (*per capita*) is around 246 €·PE^{-1}. But, as usually expected, this average unit cost increased (+26%) for smaller facilities (PE≤ 500 inhab.) and decreased (-35%) for the bigger ones (PE> 500 inhab.).

The great variability of the values observed in this survey related with the unit cost of construction per WWTP surface (27-294 €·m^{-2}) could be explained by the fact that some systems (lower values) have been designed and constructed by the municipalities, unlike those who were executed by private companies of specialty, which present the highest cost values.

The operational and maintenance (O&M) costs were not examined in this study for lack of consistent information, but based on references in the literature they are usually higher in the conventional systems, due to the need of more technical expertise, energy consumption and frequent maintenance requirement of electromechanical components. The energy costs associated to CW systems are relatively low when compared with those of conventional treatment systems. It is a solution with high energy efficiency especially for populations less than 500 inhabitants [26]. In similar Spanish HSSF CWs, O&M costs range from 5 to 183 €·PE^{-1}year^{-1}, with an average value of about 58 €·PE^{-1}year^{-1} [16].

The average value of the specific system surface is about 4.5 m^{2}·PE^{-1}, while the average value of the specific MB surface is about 2.0 m^{2}·PE^{-1}.

There is also noted that the use of smaller surface per capita does not necessary imply a worst performance of the CW systems (e.g., Vila de Rei and Alcochete WWTPs).

3.2 Environmental indicators

The performance evaluation of CW, related with pollutant removal efficiencies, was carried out only in half of the systems studied, due to the inconsistency of some data. The concentrations values of wastewater quality parameters in the influent and effluent collected during this survey are presented in Table 4.

This analysis was focused primarily on the analysis of the average removal efficiencies of the five environmental indicators selected (BOD_5, COD, TSS, P and N) showed in Figures 4, 5, 6, 7and 8.

The results obtained confirm the good performance of these wastewater treatment systems in BOD_5, COD and TSS removals, with efficiencies ranging 75-95%, 65-91% and 79-97 %, respectively, excluding poor performance of Alcochete facility.

Table 4 – Average concentration of the five wastewater quality parameters selected

WWTP	BOD_5 (mg/L)		COD (mg/L)		TSS (mg/L)		P (mg/L)		N (mg/L)	
	Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
Alcochete	97	33	1009	318	62	23	3	2	61	34
Aranhas	298	35	610	107	570	21	6	3	80	31
Condeixa	159	22	409	78	316	21	11	6	132	47
Guarda	403	44	880	131	408	27	8	5	107	33
Madeira Island	171	9	329	27	287	17				
Penacova	554	42	937	123	290	22	12	7	78	48
Rossas	516	15	1076	58	631	9	17	1	120	31
Salamonde	267	24	474	77	257	20	11	3	97	33
Salvador	524	62	889	170	366	31	8	5	125	45
Vila de Rei	251	37	618	133	238	20				
Average	**324**	**32**	**723**	**122**	**343**	**21**	**10**	**4**	**100**	**38**

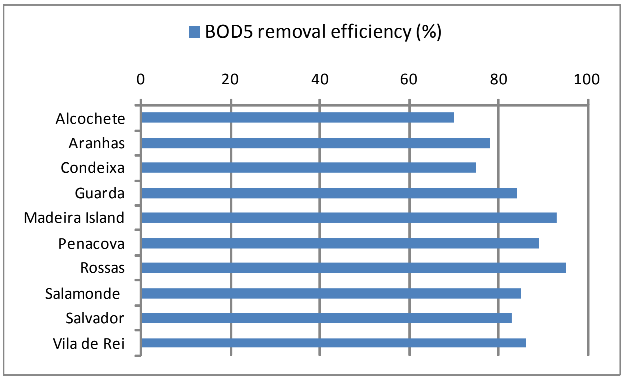


Fig.4 BOD_5 removal efficiency of surveyed CWs

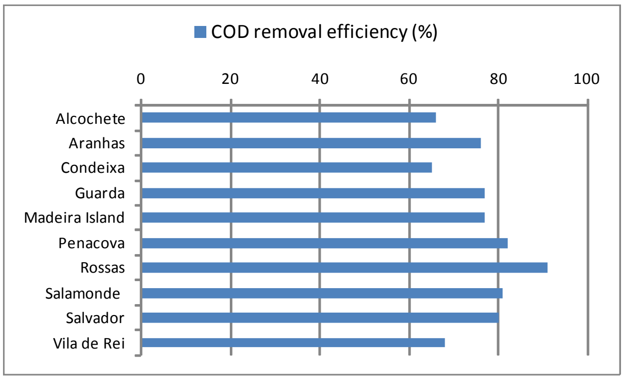


Fig.5 OD removal efficiency of surveyed CWs

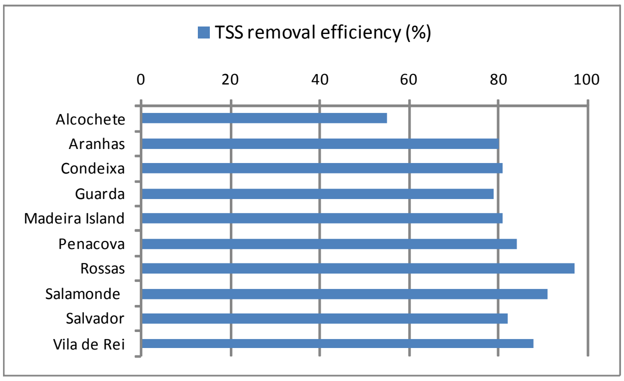


Fig.6 TSS removal efficiency of surveyed CWs

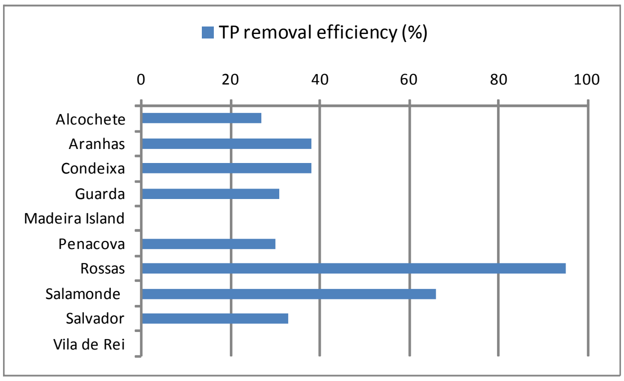


Fig.7 Total phosphorus removal efficiency s

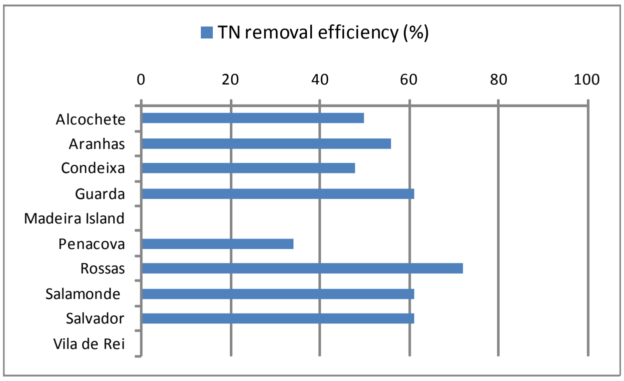


Fig.8 Total nitrogen removal efficiency

Based on the obtained results and attending to European emission limits standards, presented in Table 5, we can highlight the following main remarks [25]:

- Mean values of BOD_5 discharge comply in all situations the Portuguese Law-Decree 152/97, but the same is not happening for the Portuguese Law-Decree 236/98 (three situations occurred in which the average is above the legal limit);
- Mean values of discharge of COD are not met in two cases, by reference to any of the both Law-Decrees (LD);
- All systems meet the legal requirements for TSS;
- In relation to phosphorus, the values advocated by LD 236/98 are always met, but this did not happen in relation to the values of LD. 152/97;
- The average emission of nitrogen does not meet the legal limits.

CWs implementation as an accurate alternative to conventional methods of wastewater treatment in small communities should be carefully assessed when its effluent will be discharged to sensitive receiving waters It is crucial that CW effluent never increase their eutrophication vulnerability.

Data collected in CWs surveyed does not allow us to assess the efficiency of microorganisms' removal, like total and fecal coliforms.

However, several studies have already shown a good performance of such natural systems in terms of disinfection. This issue may make this solution even more competitive in the conventional treatment of sewage that has high costs of disinfection.

Table 5 – Emission Limit Values (ELVs) specified in current legislation

Quality Parameters	Unit	Emission limit value	Emission limit value	Minimum efficiency (%)
		LD 236/98	LD 152/97	
BOD_5	mg O_2/L	40	25	70 - 90
COD	mg O_2/L	150	125	75
TSS	mg/L	60	35	90
Total Phosphorous	mg P/L	10	2	80
Total Nitrogen	mg N/L	15	15	70 - 80

4 Conclusions

This work presents the results of performance evaluation of twenty Portuguese HSSF-CW systems.

The average removal efficiencies of pollutants were high for BOD5 (84%), COD (76%), TSS (85%), and, in most cases, the effluent quality was in compliance with the ELVs defined in Portuguese and European standards.

The same does not occurred with the emission values of nutrients, preventing its use in receiving waters bodies subjected to eutrophication processes. The average removal efficiencies found for nutrients were around 45% for TP and 55% for TN.

The average unit cost of construction (*per capita*) is around 246 €·PE^{-1}, considering all the CWs surveyed. This average unit cost increased (+26%) for smaller CW facilities (PE ≤ 500 inhabitants) and decreased (-35%) for the bigger ones (PE > 500 inhabitants).

The survey carried out of the main problems associated with the operation of the systems studied showed that only 30% of systems had been operating without any problems, giving the remaining problems of clogging of the beds, identified as the main problem of this kind of wastewater treatment system.

This is directly linked to the high percentage of systems without an accurate monitoring program for the quality control of treatment processes, focusing only on compliance with the standards of discharge and, for economic reasons, only analyzes the treated effluent. It is also neglected the issues related with the CW hydraulic behavior, like the head loss control and design parameters measurements (like flow rate, retention time and hydraulic loading).

The results obtained in this work encourage the development of future studies to increase the performance of these wastewater systems based on a better knowledge of the influence of hydraulic conditions in the pollutants removal efficiencies.

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