Design considerations for constructed wetlands in dry and hot countries

This paper discusses special considerations for design of constructed wetlands implemented in countries with dry and hot climate.

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Abstract

This paper presents examples of constructed wetlands (CWs) implemented in dry and hot countries. The design of CW treatment systems in Egypt, Palestine and Morocco is described and recommendations for application of CW technology under these environmental conditions are given.

Introduction

Constructed wetlands (CWs) are engineered water treatment systems that optimize the treatment processes found in natural environments. CWs efficiently treat different kinds of polluted water (e.g. Kadlec and Wallace, 2009). Compared to conventional systems CWs are large and extensive systems which require only low efforts in operation and maintenance. This makes CWs suitable solutions for treatments of waters in remote areas (e.g.; Headley and Nivala, 2012).

CWs have been applied in a numbers of countries with hot and dry climates (e.g. Mandi et al., 1998; Masi and Martinuzzi, 2007; Masi et al., 2010; Auborn et al., 2012). For applications in hot and dry climates usually reuse of water plays an important role and thus water loss should be minimised. This can be achieved through (Headley and Nivala, 2012):

- Selection of plants with a high water use efficiency to minimise evapotranspiration losses, and

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If treated wastewater should be reused water losses have to be avoided. This can be achieved by i) Selection of more efficient plants to minimise evapotranspiration losses, and or ii) Smaller footprints of the treatment system to avoid evaporation.

- When treated wastewater should be reused the treatment efficiency should match the quality needed for the specific reuse purpose limiting the treatment performances to the really needed ones. Segregation of wastewater and separate treatment of greywater can help in obtaining a higher amount of effluent with the proper quality available for the reuse.
- Vertical flow beds might be preferred to horizontal flow beds in order to minimize evapotranspiration losses due to their intrinsic shorter Hydraulic Retention Time in comparison to the other CW typologies; depending on the required effluent quality and reuse aim, VF beds can be filled with coarser sand, up to the smallest gravel available on site, in order to reduce the retention time (as well the performances in terms of pollutants removal).
- Horizontal flow beds are simpler in construction and operation as no intermittent loading is required and enhance the flexibility of the treatment whenever there is a high variation in hydraulic and organic loads, due to the higher volume of water contained in the reactor and the related buffering effect.
- Organic loads of CWs in hot countries can be higher compared to temperate climates. The available results, even though referred to few experiences, are showing that the organic load can go up to 10-30 times higher values in comparison to the usual ranges applied in Europe or North America.
- An initial commissioning phase where the water level is kept high is favoring the plantation success.

- Technology selection to optimise areal treatment efficiency and reduce evaporation from exposed water surfaces.

CWs can be subdivided into two main types, surface flow and subsurface flow CWs. In subsurface flow (SSF) CWs, in contrary to surface flow or free water surface CWs no free water level is visible. SSF CWs are subdivided into horizontal flow (HF) and vertical flow (VF) systems depending on the direction of water flow through the porous medium (sand or gravel). To prevent clogging of the porous filter material, the use of traditional SSF CWs is limited to mechanically pre-treated wastewater, which contains a low content of particulates (Kadlec and Wallace, 2009).

When treated wastewater should be reused the treated water quality should be in line with the requirements for irrigation, e.g. nutrients such as nitrogen and phosphorus would be required in the irrigation water. However, experience shows that this is often not in line with standards for wastewater treatment that require nutrient removal. Therefore there would be need for realistic standards that are related to the desired reuse.

In the paper the author's experiences with constructed wetland in Egypt Palestine and Morocco are presented.

Examples of CWs implemented in dry and hot countries

SEKEM farm, Egypt

The SEKEM farm wastewater and reuse work was designed to implement a constructed application of a simple, low cost, low energy and sustainable technology for the treatment and reuse of municipal wastewater through the MEDAWater European Program Support Action (Table 1, Figure 1). The treated wastewater is used for irrigation of forest trees: the irrigated land is originally desert sandy soil that is deprived from any kind

Table 1: Design data for the SEKEM farm CW

Parameter	Unit	Value
Size	PE	250
Flow	m^3/d	20
Mechanical pre-treatment	-	sedimentation tank, total volume 56 m^3
Type of CW	-	Single bed, HF
Total surface	m^2	200
Hydraulic retention time	d	2.3
Organic loading rate	g $BOD_5/m^2/d$	75
Reuse after treatment		Yes, for irrigation; The treated wastewater is reused for irrigating timber plantations as well as protecting the groundwater and improving the texture of the irrigated desert sandy soil
Special considerations during design		The design aimed to strongly reduce BOD and bacterial concentrations with the minimal HRT, reducing the total area and the evapotranspiration rate.

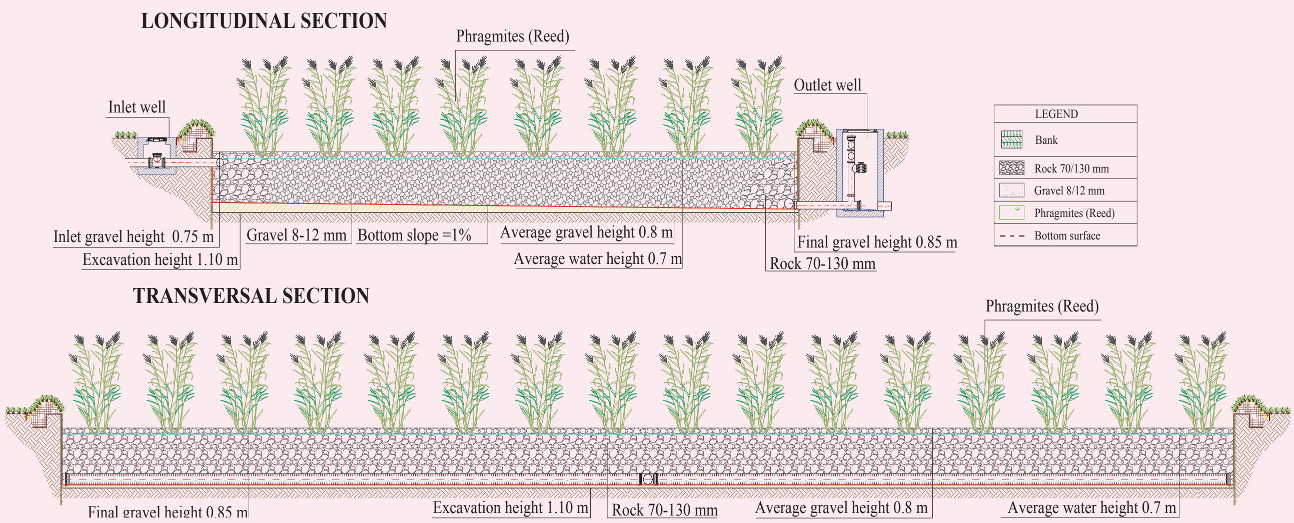

Figure 1: Schematic sketch of the SEKEM farm CW.

of nutrient elements and lack of any organic matters. The sludge is dewatered over sludge drying beds of another constructed wetland. The CW, implemented in 2007, is a horizontal subsurface flow system with a total surface of 200 m². Due to the special type of agriculture at SEKEM, organic vegetables and medicine plants grown under anthroposophic rules, wastewater will not be used on the main farm crops. It will be reused on timber plantations for packaging of the SEKEM products, which is economically very interesting.

The SEKEM farm is producing natural drugs by growing various herbs and extracting the active substances from them by an industrial cycle that ends up in the final products. It's a community, a few hundred people are living and working there and there's also a school for about 500 students.

The target area for the pilot project comprises the school of the farm, a few buildings, the campus kitchen and a laundry room. The wastewater is composed of 100 % domestic wastewater; the daily flow was calculated once from the water demand and secondly according to the number of people connected: 500 students at 20 l/day, plus 100 persons at the offices at 20 l/day, laundry plus residential houses leading to a total 15 m³/day. The SEKEM administration is going to extent the school and boarding school which would lead to a flow of approximately 20m³/day.

The design data regarding pollutant concentrations are higher than inlet monitoring data that seems to indicate a lower number of person equivalents (PE) or a higher flow (and consequently a lower HRT). However, the performance of the HF beds is good and the system permits to reach the limits of Egyptian law (Table 2).

Palestine

Oxfam Italy designed and constructed several CWs for treating greywater in some Palestinian villages in the South regions of West Bank. The greywater treatment constructions are inserted in several project founded by EC and other sponsor for the emergency support to the herders and Bedouins communities. Currently 6 CWs for greywater treatment and reuse are implemented in the

Table 2: Performance data for selected parameters for the SEKEM farm CW (average values, N = 30)

Parameters	Raw WW	Sedimentation tank effluent	Wetland Effluent	Overall Removal	Permissible limits[2]	Guidelines[2]
	mg/L[1]	mg/L[1]	mg/L[1]	%	mg/L[1]	mg/L[1]
pH	6.8-8.3	7.3-8.1	7.1-8.3	-	6.5-9.0	-
COD	800	394	174	78.2	600	400
BOD_5	357	193	103	71.3	300	150
Ammonia N	53.5	55.6	21.8	59.3	-	-
TN	94.4	69.9	43.5	53.9	-	100
TSS	217	83	33	89.8	350	250

[1] except pH

[2] The permissible limits of the primary treated wastewater for irrigating woody trees according to the Egyptian Law 48, No. 61-63, Permissible values for wastes in River Nile (1982) and Law 4, Law of the Environmental Protection (1994) - updating No.(44), (2000)

Table 3: Design data the CW treating greywater in Palestine (in total 6 CWs are operating)

Parameter	Unit	Value
Size	PE	70-120
Flow	m³/d	4-8
Mechanical pre-treatment	-	degreaser
Type of CW	-	Vertical Flow
Total surface	m²	30-60
Organic loading rate	g COD/m²/d	15-37
Reuse after treatment		Yes, for irrigation for fodder production
Special considerations during design		VF system are preferred to HF systems in order to minimize ET losses and enhance the flexibility of the treatment due to the high oscillations in hydraulic and organic daily loads

south of Hebron (see design data in Table 3 and Figure 2); 4 small CWs for wastewater treatment and reuse at household level are realized in the Gaza Strip (see design data in Table 4).

Other two interesting projects are carried on in the village of Sarra (Nablus) and Hajja (Al Qalqilya). The project „Making wastewater an asset: increasing agricultural production introducing irrigation by non-conventional water sources“ is managed by the NGOs GVC, PHG and UAWC and is financed by the EU (Contract number DCI-FOOD/2010/254-819). The final aim of the WWTPs realisation, over the obvious strong reduction of health risks linked to the presence of untreated wastewater in the villages, is to create a new source of water for irrigating the olive trees and increase the productivity and the related local economy. The approach using natural treatments such as CWs is still quite new in Palestine and mainly tested before on small scale applications or pilot plants; there are also some failed experiences

Table 4: Design data the CWs for treating wastewater treatment at household level, Gaza, Palestine (3 CWs currently operating)

Parameter	Unit	Value
Size	PE	10-20
Flow	m^3/d	0.5-1
Mechanical pre-treatment	-	three chamber septic tank
Type of CW	-	Horizontal flow
Total surface	m^2	30-60
Organic loading rate	g $COD/m^2/d$	15-37
Reuse after treatment		Yes, for irrigation for fodder production
Special considerations during design		HF type was selected prior to simplify the construction activities and the recovery of the materials; moreover Gaza is very flat and a VF feeding by gravity is often impossible. Finally the CW plants are designed for household level and realized closed to the buildings where a lot of children play every day: the HF systems avoid any contact with wastewater.

Figure 2: Greywater treatment CW in Al-najada, Hebron district, Palestine.

in the country mainly due to bad design or inaccurate realisations.

In Sarra (about 3500 PE) a new WWTP will be constructed (Table 5, Figure 3). The plant is composed of a pre-treatment with mechanical screen, a primary treatment with two tanks Imhoff in parallel, a secondary treatment using a 1st stage with vertical subsurface flow system (6 basins in parallel, 1500 m^2); 2nd stage with horizontal subsurface flow system (6 basins in parallel, 3000 m^2). The system will be equipped with slude drying reed beds for the sludge extracted from the Imhoff tanks.

The system in Hajja is a 2 stage VF + HF CW (after a primary grid and a primary treatment) that rehabilitated an existing CW plant for a population of around 1000 PE and it's designed in order to have the possibility to be doubled with the realisation of other two equal line of treatment as soon as the remaining part of the population (up to 3000 PE) will be connected to the treatment system (Table 6).

In both cases the effluent will be stored in a pond and reused for olive tree irrigation. These 2 systems will provide a useful example for possible replications in the numerous similar situations in the country.

Table 5: Design data the CW at Sarra village, Nablus district, Westbank, Palestine.

Parameter	Unit	Value
Size	PE	3500 (2022 scenario)
Flow	m^3/d	350
Mechanical pre-treatment	-	automatic screw screen + 2 Imhoff tanks in parallel
Type of CW	-	6 VF bed and 6 HF bed in series
Total surface	m^2	4500 (1500 VF, 3000 HF)
Hydraulic retention time	d	2
Organic loading rate	g $COD/m^2/d$	VF 1st stage: 197 HF 2nd stage: 20 Overall: 65
Reuse after treatment		Yes, for olive three irrigation
Special considerations during design		Due to the limited available area, a hybrid system was provided with a VF 1st stage filled with pea gravel (according to French systems guidelines) designed for high loading rate and fed by gravity using siphon devices. This design choice accomplished also with the goals to reduce ET losses. A final pond will be realized to store the treated water and to refine its quality.

Table 6: Design data the CW at Hajja village, Qalqilya district, Westbank, Palestine

Parameter	Unit	Value
Size	PE	1200 (2022 scenario)
Flow	m^3/d	120
Mechanical pre-treatment	-	three chamber septic tank + manual grid
Type of CW	-	VF and HF in series
Total surface	m^2	1590 (615 VF, 975 HF)
Hydraulic retention time	d	2.4
Organic loading rate	g $COD/m^2/d$	VF 1st stage: 138? HF 2nd stage: 8 Overall: 53
Reuse after treatment		Yes, for olive three irrigation
Special considerations during design		Also in this case a hybrid system was provided with a VF 1st stage filled with pea gravel (according to French systems guidelines) designed for high loading rate and fed by gravity using siphon devices. This design choice accomplished also with the goals to reduce ET losses. A final pond will be realized to store the treated water and to refine its quality.

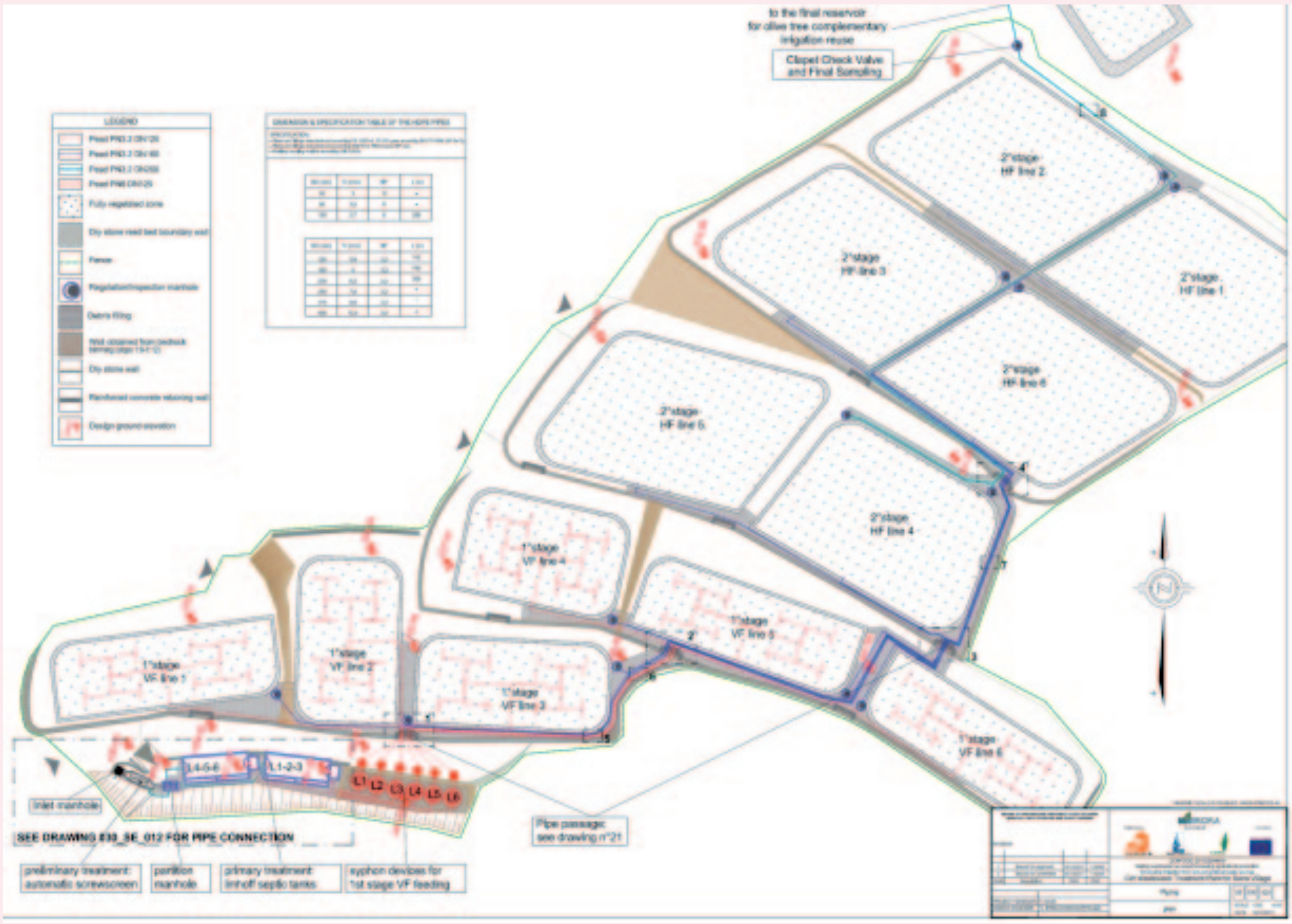

Figure 3: Schematic sketch CW at Sarra village, Nablus district, Westbank, Palestine.

Table 7: Design data the CWs for treating greywater treatment at El Attaouia, Morocco

Parameter	Unit	Value
Size	PE	100
Flow	m^3/d	60
Mechanical pre-treatment	-	automatic screw screen + 2 Imhoff tanks in parallel
Type of CW	-	6 VF bed and 6 HF bed in series
Total surface	m^2	4500 (1500 VF, 3000 HF)
Hydraulic retention time	d	0.4
Organic loading rate	g $COD/m^2/d$	40
Reuse after treatment		Yes, for olive three irrigation
Special considerations during design		Due to the limited available area, a hybrid system was provided with a VF 1st stage filled with pea gravel (according to French systems guidelines) designed for high loading rate and fed by gravity using siphon devices. This design choice accomplished also with the goals to reduce ET losses. A final pond will be realized to store the treated water and to refine its quality.

El Attaouia, Morocco

The pilot activity in El Attaouia is a partnership between the project "Sustainable concepts towards a Zero Outflow Municipality (Zer0-M)", mainly the Moroccan partner Institut Agronomique et Vétérinaire Hassan II (IAV Hassan II) in Rabat and the Municipality of El Attaouia. Zer0-M is a project in the Euro-Mediterranean Regional Programme for Local Water Management (MEDA Water programme), funded by the European Commission and the national partners of the project (Masi et al., 2010). The construction of the wetland treatment shall help to ease the difficulties in water and wastewater management faced by the fast growing rural centre of El Attaouia, a town in a dry climate with constantly increasing water consumption and very limited financial resources for the supply and sound evacuation of the amounts of water required.

The pilot plant should provide the possibility for safe reuse of greywater in outside uses (landscaping of green areas). A two stage CW treat the greywater of a Hamman to a degree to make it useable for landscaping. The filter beds are made of concrete, the first stage sitting more or less on the ground, the second completely buried. The level difference between the two beds is used to operate the batch feeding system. The first stage CW consists of a more or less continuously fed HF coarse filter. The second stage consists of a VF bed filled with fine material with batch feeding. Both beds are planted with reed (*Phragmites communis*).

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