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Review

Performance evaluation of constructed wetlands: A review of arid and semi arid climatic region

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Aiming at environmental pollution control through the use of constructed wetlands systems (CWs) in arid and semi arid climatic region, a detailed review of CWs was undertaken. Given the practical application and simplicity of the technology, principles for building phytotechnology-ecohydrology environment used for wastewater remediation is appropriate. The ability of wetlands to filter, absorb and metabolize suspended and dissolved matter is the basic philosophy behind constructed wetlands. Ecohydrology is the sub-discipline shared by ecological and hydrological sciences that is concerned with the effects of hydrological processes on the distribution, structure and function of ecosystems, and on the effect of biological processes on the elements of the water cycle. It is actually the application of science and engineering to examine problems and provide solutions involving plants. This paper reviewed the efficiency of constructed wetland in arid and semi arid conditions. The use of sub surface flow (SSF) constructed wetland as a post treatment technique have been found as promising technology for wastewater treatment in arid and semi-arid areas.

Key words: Arid, ecohydrology, efficiency, phytotechnology, sub surface flow (SSF), semi-arid.

INTRODUCTION

The threat an environment faces with technological development while using fossil fuels and other inputs for the manufacturing as well as the transportation sector are very immense. Always, nature tries to cope with the changes in the ecosystem, such as contaminants, as long as the adsorption capacity is not surpassed. The rates at which contaminants are released from the sources (point or non-point sources) as compared with the cleaning potential of the components of the eco-system (Biotic or abiotic) differ.

The major contaminant polluting fresh water ecosystem are macro and micro nutrients from agricultural fields (Barrow,1993; Mihret et al., 2013), heavy metals and carbon dioxide from manufacturing and transportation industries, organic and inorganic contaminants from municipalities and brown fields at the outskirt and inner cities (Rehm and Reed, 2000). To curb the problem of contaminants from municipalities at a certain extent, the author of this review suggested urban farming with partially treated wastewater as a feasible option (Mihret, 2013).

Depending on the effluent sources, the natures of individual contaminants vary. Some are biodegradable with limited spatial and temporal dimensions. Others needs more time and space for degradation or adsorbed by living organisms. Another category of contaminants; conservative contaminants, retain their existence but take part in the assimilation and dissimilation processes. The non-conservative contaminants participate in the assimilation and dissimilation process and are liable for chemical changes. Their destiny may be photochemical degradation, chemical or microbial transformation (Figure 1).

The application of constructed wetlands to facilitate

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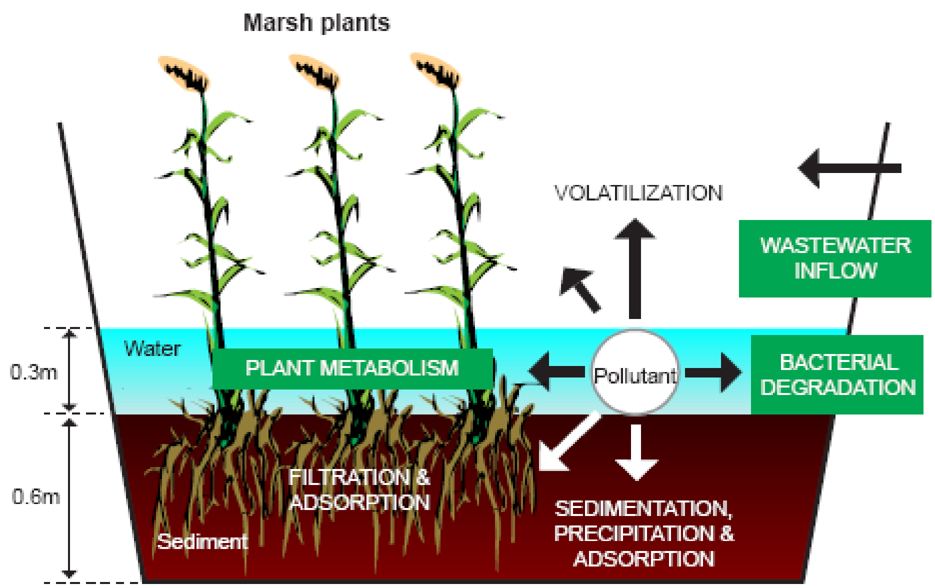

Figure 1. Pollutant removal processes in a constructed wetland system (Wetlands International, 2013).

these processes is a young post treatment technique used in developed countries. How effectively does it purifies contaminated environment? Could be a major question pointed out in relation to constructed wetlands. Competitive efficiency and effectiveness when compared with other techniques leads to the desired sustainability; which calls for evaluation of the existing constructed wetlands in arid and semi arid conditions for proper articulation of future processes.

In the following sections ecohydrology and phytotechnology concepts in the process of sludge treatment are presented, followed by constructed wetland efficiency determination, discussion and finally a conclusion.

Objectives

The plant-water-soil-microorganism interaction plays a major role in the ecohydrology concept. Soil microorganisms and plants connect the lithosphere, hydrosphere and the atmosphere.

The strength of the interaction determines the reliability of the bridge in transferring the contaminated input to environmentally friendly output (Wetland International, 2013). Investigating the efficiency of constructed wetlands in arid and semi arid conditions are the major objective of this paper.

ECOHYDROLOGY AND PHYTOTECHNOLOGY

Ecohydrology is the subdiscipline shared by ecological and hydrological sciences that is concerned with the effects of hydrological processes on the distribution, structure and function of ecosystems, and on the effect of biological processes on the elements of the water cycle (UNEP, 2004). Phytotechnology describes the application of science and engineering to examine problems and provide solutions involving plants (UNEP, 2004). Examples of phytotechnology applications include (UNEP, 2004):

1. The use of plants to reduce or solve pollution problems. Example, the use of natural wetland (W_n) for wastewater treatment.
2. The replication of ecosystems and plant communities to reduce or solve a pollution problem. Examples, constructed wetlands for treatment of wastewater or diffuse pollution sources.
3. The use of plants to facilitate the recovery of ecosystems after significant disturbances. Examples are coal mine reclamation and the restoration of lakes and rivers.
4. The increased use of plants as sinks for carbon dioxide to mitigate the impacts of climate change. Examples of this are reforestation and afforestation.
5. The use of plants to augment the natural capacity of urban areas to mitigate pollution impacts and moderate energy extremes. An example is the use of rooftop vegetation or “green roofs”.

Plants possess the ability to absorb carbon dioxide in the process of assimilation from the atmosphere to emit oxygen and thus purify air (Cavalcanti, 2003). Furthermore, in the last three decades, scientists in Europe and America mimicked the way nature coped up polluted environment, and used these naturally pollution adaptive techniques to treat sewage in sewage works, as well as recently to detoxify soil (Rehm and Reed, 2000) and

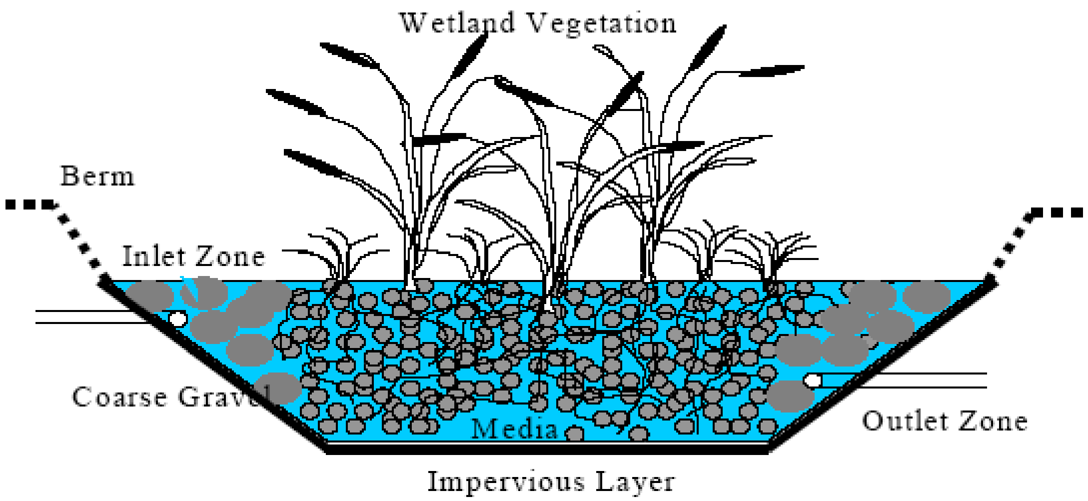

Figure 2. Subsurface flow constructed wet land (Sauer and Kimber, 2001).

sludge using constructed wetlands. Constructed wet lands are among the different techniques used in this field. Constructed wetlands are either free surface flow (FSF) type or sub surface flow type (SSF). The next section deals with the philosophy behind constructed wetlands.

Constructed wetlands

The ability of wetlands to filter, absorb and metabolize suspended and dissolved matter is the basic philosophy behind constructed wetlands. Scientists and engineers are very interested and now working together to mimic these natural systems for handling wastewaters and agricultural run-off (UNEP, 2004). This has prompted the construction of artificial wetlands to cope with the diffuse pollution originating from agriculture, septic tanks, and other sources. In some countries, for instance the U.S., legislation prohibits the drainage of wetlands unless another wetland of the same size is constructed elsewhere (UNEP, 2004).

Constructions of artificial wetlands look like an attractive and cost-effective phytotechnology concept that can be used for controlling various types of wastewater (UNEP, 2004). These wetlands are usually constructed so that water flows primarily over the sediment and through vegetation, or as vegetated submerged bed systems in which water flow is engineered for contact with plant roots.

They are excavated with a shallow gradient in soils of low permeability (Wetland International, 2013; UNEP, 2004) (or lined with an impermeable barrier and then filled with an appropriate soil). They are then either planted or vegetated naturally. Based on the hydrologic scenario in the basin, constructed wet lands are classified into two classes; sub-surface flow and free surface flow types.

Sub-surface flow wetlands

These are shallow excavations (1-1.5 m deep) with a synthetic or clay liner to prevent infiltration of water. They are filled with a media through which the liquid to be purified must flow. All in all, the water flows under the surface of the ground. The filter media can be anything from soil to light, expanded clay aggregate, but 5-10 mm gravel (Wetland International, 2013) is the most common. An inlet zone (Figure 2) made from soil aggregates of larger size ensure the influent liquid is distributed effectively into the media.

A similar outlet zone collects the treated liquid in drainage pipes which pass through the liner into a level control chamber where a simple plastic tube or swivel pipe allows the liquid level in the wetland to be controlled. Area requirement for a sub surface flow depends on the daily BOD_5 loading. The following relation (Equation 1) can be used for calculation (Wetlands International, 2013).

$$A_h = KQ_d\,(\ln C_o - \ln C_t) \qquad (1)$$

Where, A_h = surface area of bed, m^2
K = rate constant, m d^{-1}
Q_d = average daily flow rate of wastewater ($m^3\ d^{-1}$)
C_o = average daily BOD_5 of the influent (mg l^{-1})
C_t = required average daily BOD_5 of the effluent (mg l^{-1})

The value of K = 5.2 was derived for a 0.6 m deep bed and operating at a minimum temperature of 8°C

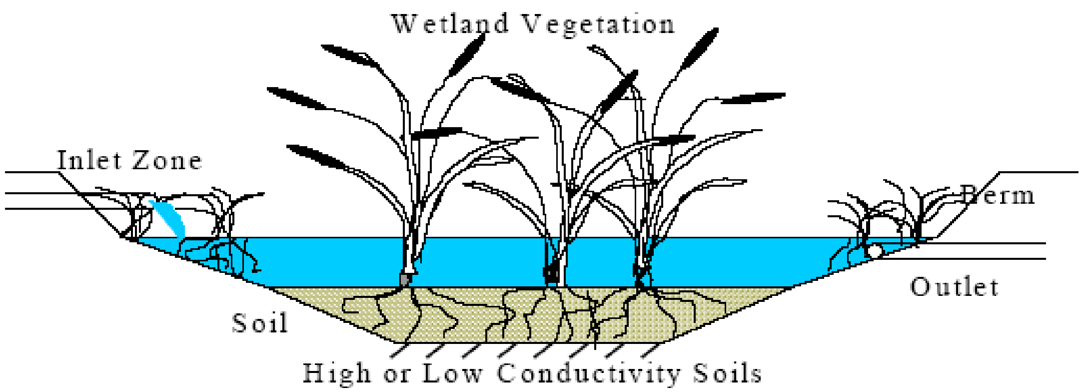

Figure 3. Free surface flow constructed wetland (Sauer and Kimber, 2001)

(Wetlands International, 2013). For less biodegradable wastewater, K-values of up to 15 may be appropriate. Using this formula, a minimum area of 2.2 m^2 $capita^{-1}$ is obtained for the treatment of domestic sewage. In practice, most design systems operate on the basis of 3-5 m^2 cap^{-1} (Wetlands International, 2013).

Free surface flow wetlands

Most free surface flow wetlands are artificial shallow marshy lands or shallow ponds filled with aquatic plants (Wetlands International, 2013). They are very shallow excavations or shallow earth banked lagoons enclosing an area of land demarcated for the purpose. The name free surface comes from the thin free water layers which are formed at the surface (Figure 3).

Soil or some other media such as gravel provides the growing media for the marsh plants. To avoid short-circuiting the surface should be virtually flat with a very gentle slope towards the outlet end (Wetlands International, 2013). The inlet zone distributes the waste-water (Figure 3) over the inlet end of the wetland, and a collection channel collects the treated liquid at the outlet end. The wastewater flows along the surface allowing settlement of solids and coming into contact with the bacterial populations on the surface of the media and plant stems.

These wetlands can serve small communities as natural wetlands and can be incorporated into the treatment systems for larger communities as well (UNEP, 2004). They can also be constructed to treat agricultural runoff or other non-point sources of pollution and are especially well suited for use in surface-mined areas (UNEP, 2004). This reference also mentioned additional ecological advantages, such as nitrogen and saltwater filtering, supply of water and nutrients, production of food and support of endangered species that can possibly increase the economic advantages as compared to conventional wastewater treatment plants.

In general, the effectiveness of phytoremediation technique in constructed wet lands depend on: geology of the site selected, hydrogeology, aquifer characteristics, soil conditions, air quality, climatic conditions, geochemistry, type and distribution of microorganisms, presence and distribution of contaminants and vegetation (UNEP; 2004). Vegetation type and characteristics, microorganism type and distribution, and soil characteristics remains influential through out the life time of constructed wetlands. Better insights of these three parameters are very crucial when dealing with the effectiveness and efficiency of constructed wetlands. In the following sections, some facts about sludge microorganisms, site soil conditions and plants adaptive to highly sludge loaded wastewater and their role in waste water treatment are presented.

Vegetation

Hydrophytes (wetland plants) serve as storage sites for carbon and nutrients and play a role in the movement of gases to and from the hydrosol (wetland soils) (UNEP, 2004). Oxygen is transported from the air through the plant into the rhizome (root zone) and from the soil too. Special types of plants (plants having aerenchym tissue) which are capable of trapping atmospheric oxygen to incorporate it into the soil with their root system are preferred for constructed wetlands. This process ensures that aerobic respiration can be maintained by the non-photosynthetic portion of the hydrophyte tissues; aerenchym tissue; that are buried in the anoxic hydrosol (Wetland international, 2013). Through symbiotic relation-ship some of this oxygen becomes available to the microbes associated with the rhizome.

Various plant species can be used in constructed wetlands (De Sousa et al., 2003). Depending on the nature of the plants they can be used for shallow marsh, marsh and deep marsh lands. Some of this plant species are presented in Table 1.

Table 1. Wetland plant species (Source; Wetland international, 2013).

Planting zone	Common name	Scientific name
	Common Reed	*Phragmites karka*
	Spike Rush	*Eleocharis dulcis*
	Greater Club Rush	*Scirpus grossus*
Marsh and deep marsh (0.3-1.0 m)	Bog Bulrush	*Scirpus mucronatus*
	Tube Sedge	*Lepironia articulata*
	Fan Grass	*Phylidrium lanuginosum*
	Cattail	*Typha angustifolia*
	Golden Beak Sedge	*Rhynchospora corymbosa*
Shallow marsh (0-0.3 m)	Spike Rush	*Eleocharis variegata*
	Sumatran Scleria	*Scleria sumatrana*

Soil nutrients

Hydrophyte growing in the constructed wetland as well as microorganisms in the soil needs optimum level of nutrients in the soil. The levels of essential nutrients control how well the plants (and microbes) grow. For optimum growth, plants require a certain ratio of specific nutrients.

If this nutrient ratio is not balanced, plant and microbial growth is badly affected. Unbalanced nutrient availability affects the growth rate of preferred microbes for waste treatment. Unbalanced ratios change the microbial population and generate smelly metabolites from anaerobic pathways with sulfur and nitrogen containing compounds (Rehm and Reed, 1999).

Microbial activity

Wetland bacteria consume the water soluble organic compounds such as hydrocarbons and BOD (see the reverse mineralization processes in the above reaction). Bacteria contain unique enzymes which allow them to metabolize the suspended organic compounds. In the dissimilation process, the aerobic bacteria produces metabolites which are incorporated into cell mass, used as energy, and/or are converted to nontoxic biological wastes (Rehm and Reed, 1999). Water soluble organic compounds are used as an energy or carbon source by other bacteria, fungi and hydrophytes. Another specific example could be the conversion of ammonium to nitrate by the bacteria nitrosomonas.

$$NH_4^+ + 2O_2 \xrightarrow[\text{Bacteria}]{} NO_3^- + N_2 \;\; H_2O$$

This reaction to get to completion about 4.6 mg.L^{-1} of oxygen is required per gram of ammonia nitrogen (Cheremisinoff et al., 1990). The optimum combined effect of all the parameters stated above gives optimal effectiveness and efficiency for constructed wetlands. Constructed wetland efficiency evaluated in arid and semi arid climatic conditions are presented in the following section.

APPROACH

Analysis on the performance of constructed wetlands was done to evaluate research outputs in arid and semi arid climatic regions. Research outputs based on the numbers of papers published in over 13 journal sources, web pages and papers accepted for publication from presentation on an international conference on constructed wetlands for water pollution control were used for this review.

In view of the current demand of this review, the performance assessment assignment employed a range of tools to gather and analyze data from secondary sources. The review approach considered and used specific indicator parameters important for the environment. The parameters used include:

1. Chemical oxygen demand (COD)
2. Biological oxygen demand (BOD)
3. Total suspended solids (TSS)
4. NH_4-N (ammonia nitrogen)
5. Total Kjeldahl nitrogen (TKN)
6. Total phosphors (TP)
7. Fecal coliforms (FC)

Relevant research documents have been reviewed during data collection and thoroughly reviewed during the preparation of this report. The data collected includes a summary of performance reports, scientific reviews and project completion reports and others.

Performance indicator parameters were computed as a percentage of pollutant reduction as compared to its initial pollutant level. The specific methods used for the study was presented below each case studies investigated.

Findings from a case study held in arid climatic condition (Egypt) and another in semi arid climatic condition are investigated. In addition, a summary of the efficiency of constructed wetlands in tropic and sub-tropic condition are taken from a PhD work of Hristina Bojcevska (Bojcevska, 2010), PhD student in Ecology/Wetland Engineering, Linköping, Sweden. The main intention of this study paper was to find an effective wetland type that can best suit arid and semi arid conditions.

Case study 1: Combining UASB technology and constructed wetland for domestic wastewater reclamation and reuse (El-Khateeb and El-Gohary, 2003)

In this paper the performance efficiency of constructed wetlands in Egyptian conditions are compared. For the study, two treatment schemes consisting of an up-flow anaerobic sludge blanket reactor (UASB) followed by either subsurface flow (SSF) or free surface flow (FSF) constructed wetlands have been investigated. UASB reactor can be briefly described as a system in which substrate passes first through an expanded sludge bed containing a high concentration of biomass (Cavalcanti, 2003; De Sousa et al., 2003).

The sludge in the reactor may exist in granular or flocculent form, but the granular sludge offers advantages over flocculent sludge.

Most of the substrate removal takes place in sludge bed. The remaining portion of the substrate passes through a less dense biomass, called the sludge blanket. The common macrophyte in Egypt *Typha latifolia* (cattail) was used at a planting density of three rhizomes m^{-2}. To evaluate the role of plants in the treatment process, an unplanted gravel bed identical to the SSF unit was operated as control.

During the study period, the wetlands were fed with the UASB effluent at an organic loading rate ranging from 17.3 to 46.8 kg BOD_5/ha·d (55.1 to 134.6 kgCOD.ha^{-1}·d^{-1}). Effectiveness of the system for the removal of key constituents (COD, BOD, TSS, nutrients and FC (fecal coli form) has been investigated.

The results show that, the level of COD_{tot}, and TSS in the final effluent of SSF was lower than that of FSF. The possible justifications could be low flow velocity and higher surface area in the SSF media and lower microbial activities as a result of temperature variation in the case of FSF media.

Subsurface flow wetland has demontrated higher overall efficiency than the unplanted control. FC count showed FSF media's superiority over the control and SSF. The reason could be the possible exposure of the bacteria's for UV in the case of FSF. BOD_{tot} showed more or less the same pattern in both SSF and FSF media (Table 1).

Case study 2: River water quality improvement by natural and constructed wetland systems in the tropical semi-arid region of Northeastern Brazil (Ceballos et al., 2001)

In this paper the performance efficiencies of a natural *Typha* spp. wetland (W_n) and constructed wetland (W_c, SSF type) were compared in northeastern Brazil (Paraiba State). The summary of the outcomes from the evaluation are presented in Table 3.

In the natural wetland, removal values were: 75 and 81% BOD_5; 10-53% total phosphorus; 13-55% ammonia; 89-91% FC. Constructed wetland removals increased with HRT with best results on 10 day. Observed removal values were: 74-78% BOD_5; 58-82% ammonia; 94-98% FC. Despite the high remaining values of FC (1.4 x 10^4CFU in 100 ml), the removals were satisfactory and hydraulic retention time (HRT) dependent, suggesting a gradual optimization of the system with time. The W_c exhibited good efficiency for improving water quality from polluted river.

On her PhD work, Bojcevska (2010) did a summary of the research findings of four different researchers who made their researches using different macrophytes other than *Typha* spp. Here this summary is presented to justify the factors which affect the performance efficiency of the two types of constructed wetlands. Different efficiency values are observed as a function of (Tables 2, 3 and 4):

1. Different types of constructed wetlands used
2. Types of hydrophytes used
3. Hydraulic loading rate
4. Hydraulic retention time

CONCLUSION

A Well-designed constructed wetland can perform better than natural wetlands due to easier control and management (Babatunde et al., 2008). Removal efficiencies of different types of constructed wetlands are different.

FSF wetland is better in some aspects (FC removal) than SSF. SSF wetland also showed some superiority over FSF. Even though both of them showed a similarity in BOD_5 removal, SSF wetland showed higher efficiency in COD and TSS removal.

The type and constituents of waste water in the effluent side deter-mines the type of constructed wetland to be used. For waste water rich in fecal coliform and nitrogen, FSF wetland could be a better preference than SSF. For waste water rich in COD, TSS and TP, SSF is a good choice.

Therefore, appropriate decision during wetland construction affects the performance of the system. Performance efficiency can also be dependent on climatic conditions, hydraulic retention time, macrophytes

Table 2. Main characteristics of the sewage measured at the out let of raw sludge conduit, ASB reactor, SSF and FSF wetlands (standard deviation in brackets) (El-Khateeb and El-Gohary, 2003).

Sludge characteristic	Effluent measured at the out let of			
	Raw sludge	UASB Reactor	Constructed wetland type	
			SSF	FSF
COD_{tot} (mg/L)	620.9 (±189)	241 (±66)	53(±19)	3(± 26)
BOD_{tot}(mg/L)	282 (±68)	99 (±27)	22(±(8.5)	20(± (8)
TSS (mg/L)	191 (±68)	59 (±24)	12± (5.5)	26(± 17)
NH_4-N (mg/L)	31 (±5.5)	33 (±5)	24(±6.6)	16(±5)
TKN(mg/L)	61 (±20)	55 (±16)	40(±15)	32(±16)
TP(mg/L)	5.2 (±1.6)	3.4 (±0.7)	2.1(± 0.9)	2.4(±1)
FC (CFU/100 ml)	2.4×10^9 (±2.18×10^9)	1.8×10^8 (±2.5×10^8)	8.3×10^4 (±9×10^4)	7.2×10^4 (±8.5×10^4)

Table 3. Summary of the efficiency observed in natural and constructed wetlands (Ceballos et al., 2001).

Effluent characteristic	Natural wetland (W_n) average efficiency (%)	Constructed wetland (W_c) average efficiency (%)	Remark
BOD_5	78	76	Constructed wetland showed relatively modest efficiency over the natural one
TP	24	12	
NH_4-N	27	70	
FC	90	90	
SS	50	66	

Table 4. Performance efficiencies in relative percentage of some constructed wetlands (CW) located in tropical and subtropical regions concerning a selected number of water quality parameters.

CW type	Area (m^2)	HLR (m/d)	HRT (d)	Mean influent concentration (mg/L)		Reduction in concentration (%)		Reference
FSF	300	-	7-12	COD	155.2	C.P	63	Okurut et al. (1999) as cited by Bojcevska, 2010
						P.M	43	
				PO_4	3.71	C.P	16	
						P.M	37	
SSF	n.i	6.48	n.i	SS	104.8		80	Mashauri et al. (2000) as cited by Bojcevska (2010)
				COD	100.8		66	
		55.2	n.i	SS	101.8		50	
				COD	125.8		50	
FSF and SSF	10	0.018	12.8	PO_4-P	2.39		69	Lin et al. (2002) as cited by Bojcevska (2010)
		0.034	6.8		10.45		45	
		0.135	1.7		5.19		35	
SSF	9.36		5	TRP	15,5	C.P	83	Kyambadde et al. (2004) as cited by Bojcevska (2010)
						M.V	48	

n.i = No information; C.P = *Cyperus papyrus*; P.M = *Phragmites mauritianus*; M.V = *Miscanthidium violaceum*; FSF = free surface flow; SSF = sub surface flow, HLR = hydraulic loading rate; HRT = hydraulic retention time.

growth rate and type, root zone maturity and biofilm formation, substrate characteristics and rate of microbial growth and activity. Selecting an appropriate substrate media that suits the type of available hydrophyte species facilitates better removal efficiency. It is essential to avoid the introduction of an invasive hydrophyte species which does not belong to the prevailing wetland ecosystem (personal view). Constructed wetlands are not recommended for treatment of raw waste water. Combining SSF with UASB gives a higher performance efficiency and longer operation time. The different scenarios presented shows that the use of SSF wetland as a post treatment technique after a UASB reactor is a promising technology for wastewater treatment in arid and semi-arid areas.

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REFERENCES

Babatunde AO, Zhao YQ, O'Neill M, O'Sullivan B (2008). Constructed wetlands for environmental pollution control: a review of developments, research and practice in Ireland. Elsevier , Environment International, 34 (1):116-126.

Barrow Chris (1993). Water Resources and Agricultural Development in the Tropics. John Wiley and Sons, Inc., New York, USA.

Bojcevska H (2010). Treatment performance of a free water surface constructed wetland system receiving sugar factory effluents in the Lake Victoria region, PhD thesis. (IFM/Department of Biology, University of Linköping, Linköping, Sweden) online at : http://www.ifm.liu.se/~inuita/researchproposal.html

Cavalcanti PFF (2003). Integrated Application of the UASB Reactor and Ponds for Domestic Sewage Treatment in Tropical Regions. (Thesis; Wageningen University, Wageningen). Online at: http://library.wur.nl/wda/dissertations/dis3368.pdf

Cheremisinoff PN,Trattner RB, Lawson BK, Newberger BI (1990). Introduction to Biotechnology for Waste /Wastewater Treatment. SciTech publishers, Inc., Matawan, NJ, USA.

De Ceballos BSO, Oliveira H, Meira CMBS, Konig A, Guimarães AO, De Souza JT (2003). River water quality improvement by natural and constructed wetland systems in the tropical semi-arid region of Northeastern Brazil. Water Sci. Technol. 44(11-12):599-605.

De Sousa J.T., Haandel A. van, Lima E.P.C and Guimarães A.V.A, (2003). Performance of Constructed Wetland Systems Treating Anaerobic Effluents. Water Science and Technology: 48. Issue 6. pp. 295-299.

El-Khateeb MA, El-Gohary FA (2003). Combining UASB Technology and Constructed Wetland for Domestic Wastewater Reclamation and Reuse. Water Sci. Technol. Water Supply 3(4):201-208.

Mihret DU (2013)). Household Level Wastewater Management: A Pilot Case Study For Hawassa Town, Ethiopia, Int. J. Engine. Res. Technol. (IJERT) , ISSN: 2278-0181 , www.ijert.org. 2:6.

Mihret DU, Ermias AD, Mekonene AG, Adunga EB (2013). Environmental Impacts of Small Scale Irrigation Schemes: Evidence from Ethiopian Rift Valley Lake Basins, Scientific J. Environ. Res. Engine. Manage. ISSN 1392-1649, ISSN (online) 2029-2139. www.erem.ktu.lt. 63:1.

Rehm HJ, Reed G (1999). Biotechnology: Environmental processes I; waste water treatment. Wiley-VCH Verlag GmbH; Weinheim, Germany, 1999.

Rehm HJ, Reed G (2000). Biotechnology: Environmental processes II; Soil Decontamination. Wiley-VCH Verlag GmbH; Weinheim, Germany.

Sauer P, Kimber A (2001). Technical Assessment of Constructed Wetlands for Wastewater Treatment in Iowa. IOWA Energy Center, November, 2001. Online at: *www.iamu.org/main/studies_reports/reports/WetlandReport/Section IIIntro.HistoryDesign.pdf*

UNEP (2004). Integrated watershed management -Ecohydrology and Phytotechnology Manual. Online at: *www.unep.or.jp/ietc/publications/freshwater/watershed_manual/index.asp*

Wetlands International - Malaysia Office (2013). The Use of Constructed Wetlands for Wastewater Treatment. Selangor, Malaysia. Online at: http://www.wetlands.org/WatchRead/Currentpublications/tabid/56/ArticleType/ArticleView/ArticleID/1369/PageID/550/Default.aspx