

Evaluation practice and performance efficiency of horizontal subsurface flow constructed wetland on wastewater treatment in East Africa countries focused on Ethiopia: a review

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Abstract

Introduction: In East Africa, constructed wetlands are rarely investigated by different scholars to test its performance in treating wastewaters at pilot scale levels. Horizontal subsurface flow constructed wetland is researched for its performance, but information's are existed in a scattered way which is unable to get complied data about its efficiency for future implementation.

Objective: This systematic review was aimed to assess the practice and performance efficiency of subsurface wetland wastewater treatment technologies and associated factors for in East African countries in general and to Ethiopia in particular.

Methods: Comprehensive review of published works of literature which were conducted on the application of horizontal subsurface flow constructed wetlands in treating a variety of wastewaters and discusses its feasibility in pollutant removal efficiency.

Result: In abroad, the following maximum abatement efficiencies were achieved using Horizontal Sub Surface Flow Constructed Wetland (HSSFCW) treatment system: 98%, 96%, 85%, 90%, 92%, 88% for BOD₅, COD, TSS, TN, NH₄ -N, PO₄³⁻ respectively in Kenya; 98.46% and 98.55% for COD and BOD₅ whereas in Ethiopia, the HSSFCW achieved the following abatement efficiencies: COD ranges from 58 - 80%, BOD ranges from 66 - 77%, TKN ranges from 46 - 61%, sulfates ranges from 53 - 82%, and NH₄ - N range from 64 - 82.5% for tannery wastewater treatment. For domestic wastewater treatment; 99.3%, 89%, 85.5, 84.05%, 77.3%, 99% and 94.5% for BOD₅, COD, TSS, TN, PO₄³⁻, TP, Sulfate, and TFC respectively.

Conclusion: Constructed wetland performance efficiency sustainability is affected by the operational conditions of HSSFCW including plant species, media/substrate types, water depth, hydraulic loading, and hydraulic retention time and feeding mode.

Keywords: Constructed wetland, horizontal subsurface flow, removal efficiency, wetland plants, treatment technology, wastewater, Ethiopia.

Introduction

Water pollution is a serious problem globally involving the discharge of dissolved or suspended substances into groundwater, streams, rivers, and oceans. A major source of pollution in developing countries is industrial, domestic, agricultural and municipal activities and this creates a problem of wastewater disposal which could be a pollution stress on water bodies, and threatening aquatic biota and human health (Abrha et al. 2017).

Wastewater generated from different sources typically has different concentrations of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) from all the organic components (sugars, soluble starch, ethanol, volatile fatty acids, etc). Since it is economically and environmentally sound, it has been practiced in most parts of the world. Aquatic ecosystems

and their associated catchments have played an important role for humankind on all continents. Constructed wetlands technology of wastewater treatment was started in Germany around the 1960s (Mekonnen et al). Waterbody deterioration is becoming a serious issue in Eastern African countries due to indiscriminate discharge of wastewaters and lack of comprehensive management techniques. To protect public health and environmental problems, proper wastewater treatment is fundamental issue in resource scares countries for not only maintaining public and environmental health but also promoting economic development by selecting suitable, applicable, manageable with the local people, cost-effective, and environmentally friendly technology which is more and more important for a particular social, political and economic environment in overcoming the wastewater

problems. In Ethiopia, the combination of rapid urbanization and industrialization expansion increased waste volumes. Most of the wastewaters generated from either domestic or industrial sources are discharged still without adequate treatment processes. The discharging of untreated or partially treated wastewater by cities and industries causes an impact on the environment and public health due to contamination of the downstream water supplies for drinking, irrigation and recreational activities (Birhanu 2007), due to the presence of nutrients, heavy metals, toxic organic pollutants and pathogens. Research reported by Bahri et al. (2016) also agreed that untreated wastewaters are discharging into the freshwater bodies and changing the quality of freshwater. Not only deteriorate the freshwater bodies, it also changing the farmland soil characteristics due to use of contaminated river waters or direct use wastewater for irrigation.

In Ethiopia, particularly Addis Ababa is facing a high rate of sanitation problems, due to the absence of wastewater treatment facilities. The city has only one wastewater treatment plant; the Kaliti wastes stabilization ponds, which is operational since 1985. The waste stabilization pond receives 7500 cubic meter domestic wastes through the sewerage lines. (Bahri A et al). Wastewater generated from domestic and industrial sectors are disposed into the Akaki River. The surrounding farmers use this river water for the production of vegetables. The pollution of the water bodies, the health hazard related to the use of untreated wastewater for irrigation, and overall, the environmental degradations are main concerns currently. According to Bayrau et al. (2008) surveyed result, from a total considered sample of 1258 farmers on the health incidence of wastewater irrigation, the producer showed that increasing prevalence of intestinal illness.

Outbreaks of waterborne diseases in addition to eutrophication of surface water and farmland resources are commonplace. A recent literature report also showed that community health was affected due to prevented diseases of water, sanitation and hygiene-related factors (Hamere et al. 2017). Overall, water body deterioration is becoming a serious issue in Ethiopia due to the indiscriminate discharge of wastewaters and lack of comprehensive management techniques. To protect public health and environmental problems, proper wastewater treatment is fundamental issue in Ethiopia for not only

maintaining public and environmental health but also promoting economic development by selecting suitable, applicable, manageable with the local people, cost-effective, and environmentally friendly technology which is more and more important for a particular social, political and economic environment in overcoming the wastewater problems. The development of effective wastewater treatment system considering the financial aspect is an important issue for developing countries. The emergence of constructed wetland technology shows great potential as a cost-effective, energy-efficient, environmentally friendly and effective in pollutant removal efficiency (USEP 1993) which may be a suitable technology for these countries to achieve the goal of wastewater management system. The use of constructed wetlands for wastewater management is becoming more and more popular all over the world. This is due to its efficient wastewater management ability with a cost-effective options in both developed and developing countries. Most of these systems are easy to operate, require low maintenance, and have low investment cost (Langergraber et al. 2013, Vymazal 2014, Ballesteros et al. 2016). Today subsurface flow CWs are quite commonly used in many developed countries such as Germany, UK, France, Denmark, Australia, Poland, and Italy. Constructed wetlands are also appropriate for developing countries but they are rarely investigated and implemented (Prasad et al. 2016). Constructed wetlands (CWs) used to treat a wide variety of wastewaters such as domestic, municipal, industrial, landfill leachate as well as agricultural and highway runoff (Tilak et al. 2016). Wetland technologies are a reliable onsite wastewater treatment technology and works with a higher rate of biological activity which enables conversion of many of the pollutants that are contained in the wastewater into non – toxic byproducts and serve as secondary or tertiary treatment level that meets the regulatory standards. CWs have shown to successfully control macro (organic material, nutrients, and pathogens) pollutants and provide high-quality water used for irrigation, recreational and other reuse purposes. Generally, this technology serves as an active and low-cost alternative technology for the treatment of wastewater overall the world (Mustafa et al). Their effective pollutant removal is associated with several mechanisms involved in the constructed wetland systems. These are sedimentation, filtration, volatilization, adsorption, plant uptake and bacterial activity

(Langergraber et al. 2013; Vymazal 2014; Ballesteros et al. 2016). Therefore, this review paper was to provide a comprehensive literature review on the application of horizontal subsurface flow constructed wetlands in treating a variety of wastewaters and discusses its feasibility in pollutant removal efficiency in East Africa, particularly in Ethiopia.

Materials and Methods

This review paper was written using searching key phrases “HSSF (Horizontal Sub Surface Flow) practice in the world”, “HSSF practice in the in Africa, particular to east Africa and Ethiopia”, “Factors affecting treatment efficiency and “benefits and limitation of Constructed wetland” in springer link, science direct, library genesis, jester, and www.nap.org searching web pages. From these searching, peer-reviewed journals and review papers were used. The interpretation of the result of each document was done using bar graphs, lines and scatter plots in Microsoft excel. Result measurement units of sludge physicochemical parameters investigated by different scholars were reorganized and expressed in similar units for comparison.

Results and Discussion

Performance efficiency of HSSFCW: a case in other countries: The focus of each case study is according to parameters related to the overall constructed wetland design, macrophyte species, hydraulic loading rates and the efficiency of pollutant removal. To evaluate the performance efficiency of a CW unit, the percentage of concentration reduction and mass removal is reported. According to Mustafa (2013) result, the monitoring of horizontal flow constructed wetland indicates that the general performance of the system was good and it successfully reduced pollutants even under fluctuating pollutant

loading resulting from power breakdown. The average reduction of BOD concentration over the treatment periods was 50% with the mean effluent concentration of 34mg/L. whereas, the average removal efficiency of the treatment system for COD, TSS, ammonia – nitrogen, orthophosphate and fecal coliform were 44%, 78%, 49%, 52% and 98% with mean effluent concentrations of 68.3 mg/L, 45mg/L, 9.7mg/L, 3.7mg/L and 3.0 x 10³CFU/100ml respectively. The COD removal efficiency of HSSFCW even at low concentration which might be due to high degradation rate in the wastewater collection systems and in settling tank before entering the CWs. Overall, the result obtained in Indonesia, Thailand, and Costa Rica revealed that the local macrophytes and local natural substrates can perform successfully the treatment of domestic wastewater (Table 1).

Moreover, the use of macrophytes creates a green space in a single house yard or green public views for the neighborhood (Qomariyah S., 2017). The performance efficiency of subsurface flow constructed wetland in Italy done by Pucci et al. (2000) indicates that it has high removal efficiency for COD (93%), TSS (81%) and total coliform (99%), but relatively less removal for nitrates (55%), total nitrogen (50%), ammonium (30%) and total phosphorus (20%). This is mainly due to poor nitrification and denitrification in the treatment system. A study done in Kenya also revealed that the effectiveness of the constructed wetland in treating domestic wastewater and indicated that the removal efficiency of 98%, 85%, 96%, 90%, 92% and 88% for BOD₅, TSS, COD, TN, NH₄ – N and PO₄ respectively (Nyakango, 1999). This achievement was due to the wetland design which consists of a combination of a surface flow system followed by three subsurface flow wetlands in a series adjacent to it.

Table 1: The effective removal of pollutants in CWs with local macrophytes and natural substrates (Source: Qomariyah et al. 2017).

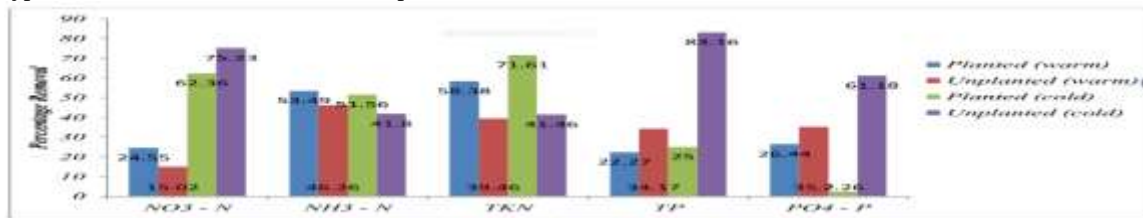
Type and size of CW	Type plant	Type of substrate	Country	Removal efficiency (%)
HSSFCW (1.7 x 0.7 x 0.7m)	C. papyrus	Sand & gravel	Indonesia	COD = 98.46 BOD = 98.55 Detergent = 99.86 TSS = 88 – 96
HSSFCW (2 x 1x 1m)	Canna & Heliconia	gravel	Thailand	COD = 42 – 83 TN = 4 – 37 TP = 6 – 35
HSSFCW (14x1.2x0.6m)	Coix lacryma jodi	Crushed rock	Costa Rica	BOD = 94 – 99.9 TSS = 91.7 – 97.9 FC = 99.99 TSS = 85%, BOD=98%, COD = 96%, TN = 90%, PO ₄ = 88%,
HSSFCW (3 x1x1m)	C. papyrus	Sand & gravel	Kenya	

Table 2: Horizontal Subsurface wetland wastewater treatment efficiency in East Africa (2013-2014).

Parameters		Country				
		Tanzania	Egypt	Ethiopia	Kenya	Uganda
COD	In	917.5+/-508.7	197+/-43.4	619.3+/-187	159.5+/-75.8	155.2+/-50.9
	Eff	36.5	71	97.8	62.1+/-18	63.3
BOD5	In	432.2+/-156	120+/-35	273.3+/-22	73.6+/-17.7	48.4+/-19.5
	Eff	66.2	82.7	89.7	68.5+/-8.6	68.0
TSS	In	128.1+/-63.8	79.3+/-28	201.3+/-6.7	103.1+/-104.1	-
	Eff	75.9	93.7	83.8	60.5+/-20.6	-
NH4+	In	26.57+/-16.15	51.8+/-18	38.7+/-6	25.8+/-4.5	54.1+/-17.8
	Eff	34.7	88.5	24.7	46.6+/-1.0	39.0
TN	In	-	53.23	107.7+/-0.8	-	-
	Eff	-	74.8	54.5	-	-
TP	In	8.54+/-0.79	4.5+/-1.7	8.9+/-0.95	36.2+/-0.2	3.71+/-0.8
	Eff	21.5	33	16.9	49.6+/-15.5	16.4
Reference		Njau <i>et al.</i> 2011	El-Khateeb & El-Bahrawy 2013	Berhanu 2007	Mburu <i>et al.</i> 2013	Okurut <i>et al.</i> 1999

The performance efficiency of different constructed wetland systems that contain different HRT, substrate, plant species, and wastewater type were reviewed to determine the performance

of constructed wetland units in the removal of pollutants. The influent, and effluent concentrations including percentage removal were summarized in Table 2.

**Figure 1: Performance of Vegetation, climate and media on nutrient removal**

The mean influent concentration of COD, TSS, NH4 – N, NO3 – N, and PO4 – P in January were 144, 54, 96, 2.76 and 3.62mg/L respectively. The effluent concentrations after treating with constructed wetland were 64, 8, 62, 1.69 and 3.55mg/L respectively. The mean percentage removal reductions for COD, TSS, NH4 – N, NO3 – N, and PO4 – P in this month were 55%, 85%, 35%, 39%, and 2% respectively. The mean influent concentrations of these pollutants in February were 192, 38, 63, 2.91 and 4.12mg/L respectively. The mean effluent concentrations were 64, 4, 28, 2.33 and 1.05mg/L respectively. The mean percentage removal efficiency of the wetland was reached 66%, 89%, 55%, 20%, and 75% for COD, TSS, NH4 – N, NO3 – N, and PO4 – P respectively. In hydrologic comparison in the constructed wetland indicated that the COD, TSS, NH4 – N, NO3 – N, and PO4 - P reductions were considerably greater in February compared to January. This was due to the lower HLR and greater HRT in February compared to January.

The major mechanisms of TSS and COD removals in constructed wetlands are the sedimentation, filtration and physical entrapment

in the void pores of the sand and gravel media. The higher HRT also allows for greater physical settling of suspended particles, which reduces the TSS and the higher residence time allows wetland plants to effectively uptake nutrients thereby reducing the effluent concentrations (Tilak *et al.* 2016). The nitrogen content of *Pistia stratiotes*, *Typha latifolia* and *Lemongrass* in the subsurface flow constructed wetland were 37.4g/Kg, 27.1g/Kg and 15.8g/Kg respectively. The phosphorus accumulation capacity of these plant species was also 8.4g/Kg, 2.96g/Kg and 2.29g/Kg respectively for *Pistia stratiotes*, *Typha latifolia* and *Lemongrass* in the constructed wetland (Tilak *et al.* 2016) (Figure 3). Subsurface flow constructed wetlands are good in utilizing pollutants in a symbiosis relation between aquatic plants and microorganisms in the media and the plant root system. Complex organic compounds contained in wastewater will be consumed by plants as a nutrient, while the root system of the aquatic plants will produce oxygen that can be used as of energy or catalyst for a series of metabolic processes for heterotrophic aerobic microorganisms.

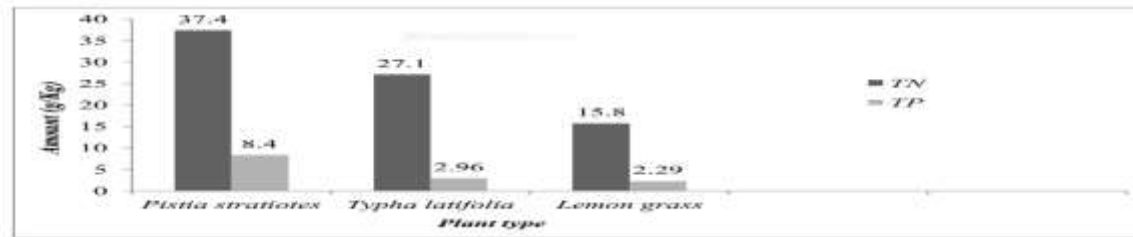


Figure 2: Nutrient accumulation in the wetland plants

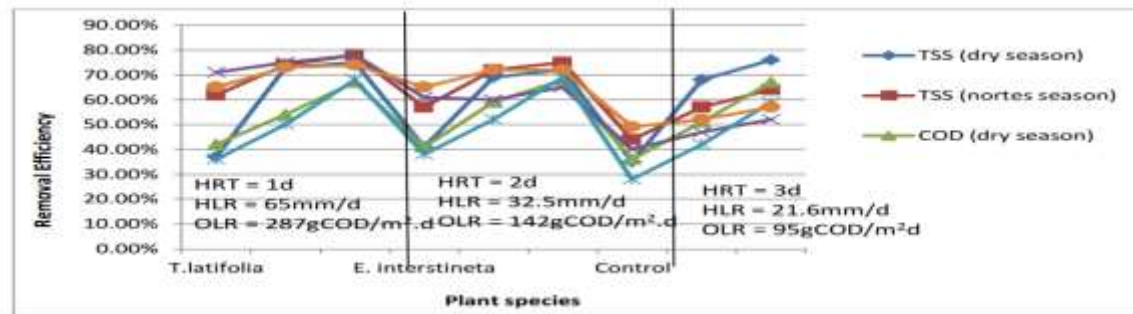


Figure 3: COD, BOD and TSS removal efficiency of HSSFCW at different seasons.

Plants that are usually used include *Cyperus alternifolius*, *Canna indica*, *Phragmites australis*, *Typha* spp., *Scirpus* spp., etc. these plants reduce the concentration of BOD, COD, ammonia, nitrites, phosphorus and bacterial contaminants (Wijaya et al. 2016). The above graph indicates that the local macrophytes and natural substrate can perform successfully the treatment of domestic wastewater. The results demonstrated that removals of organics (COD and BOD) are high in the horizontal subsurface flow constructed wetlands. The treatment efficiency of BOD and COD ranged between 76 – 99.4% and 76 – 98.46% respectively, except COD removal studied result in Thailand which varied between 42 – 83%.

Performance efficiency of HSSFCW a case in Ethiopia: In Ethiopia, environmental degradation within and downstream of cities has multiple consequences for public health, in particular through the use of untreated wastewater in irrigated agriculture and Rivers are highly affected by pollution of heavy metals, pathogens, organic compounds, synthetic chemicals, microplastics and nutrients (Teshager et al. 2014). Study reports indicated that the city water bodies and surrounding agricultural soils are contaminated with heavy metals such as Hg, As, Pb, Sb, Ni, Sr, and Cd (Tilahun et al. 2007, Elias et al. 2017) which are extremely toxic even at low concentrations and causes gastrointestinal, skin, nerve damage, lung damage, cancer, nervous and immune system, kidney damage, brain damage,

liver damage, and etc. (Kassa et al. 2012). Besides these, water, soil and air pollution due to industrial and domestic waste discharges causes peculiar diseases. Study and literature report showed that most people found in Akaki Kaliti industrial zone are affected by peculiar diseases such as cough (76.5%), diarrhea (58.8%), typhoid (51%), typhus (45.1%), gastrointestinal (39.2%), skin problem (29.4%), Asthma (33.3%), and bronchitis (3.9%) (Aregawi et al 2014, Elias et al 2017). This may be due to long term intake of food that contains high levels of heavy metals and pathogens, and contact with sediments contains heavy metals and pathogens, poses risks to human health. (Itanna et al 2002, Bekele et al 2008) Terfie and Asfaw (2004) conducted on five pilot-scale subsurface flows constructed wetlands; four units vegetated with *Cyperus alternifolius*, *Typha domingensis*, *Phragmites karka* and *Borassus aethiopum* and the fifth left as unvegetated.

The performance efficiency of each cell in removing organic matter (COD & BOD₅), Ammonium and total nitrogen including total chromium under the 5day hydraulic retention time and hydraulic loading of 120L/day showed promising results. The wastewater analysis indicated that COD reduction by 58 – 80% for an inlet organic loading rate (OLR) ranged from 2202 – 8100mg/L and BOD₅ reduction by 66 – 77% for an inlet OLR ranged from 650 – 1950mg/L. The removal of inorganic substances such as nitrates, sulfates, sulfides, total nitrogen, and ammonia- nitrogen ranged from 30 – 57%, 82

– 92.4%, 53 – 82%, 46 – 61% and 64 – 82.5% respectively (Table 2). Similarly, Kassa and Mengistou (2014) tested pilot-scale HSSFCWs efficiency in treating domestic wastewater in vegetated and unvegetated conditions at HLR and HRT of 7 days and 26L/day HLR. The result showed that the nutrient removal efficiency of HSSFCW was significantly higher in the planted species than unplanted treatment system. The average removal efficiency of orthophosphate in the treatment beds was 84.05% for *C. Papyrus*, 65.29% for *P. Karaka* and 50.20% for the unplanted. She proved that the average removal efficiency of planted cells was higher than unplanted due to the macrophytes' role to accumulate high biomass and remove nutrients. (Kassa et al. 2014).

Jehovah Witnesses Branch Office (JWBO) full-scale HSSFCW performance was evaluated by Birhanu (2007), and the result showed average removal efficiency of the constructed wetland system for BOD₅, COD, TSS, Ammonium, Nitrate, total nitrogen, orthophosphate, total phosphorus, sulfate, sulfide and total coliform was 99.3%, 89%, 85%, 28.1%, 64%, 61.5%, 28%, 22.7%, 77.3%, 99% and 94.5% respectively.

The individual cells removal efficiency indicated that the wetland planted with *Cyprus papyrus* showed higher removal efficiency for nitrate (82.4%), ammonium (24.8%), total nitrogen (54.8%), orthophosphate (23.5%), and total suspended solids (83.9%) as compared to the other wetland systems. In the same regard, wetland cells planted *Phoenix canariensis* showed higher removal efficiency for total phosphorus (17%), sulfide (99%), BOD₅ (98%), COD (90%) and total coliform (94%). Whereas, the other wetland cells planted with *Cyprus alternifolia* showed higher removal efficiency only for sulfate ion (82.2%).

The performance efficiency results indicated that this wetland system has excellent removal capability for BOD₅, COD, TSS, sulfate, sulfide and total coliform bacteria. However, since the HRT of the constructed wetland system (2.16 days), the nutrient (nitrogen and phosphorus) removal efficiency was low. The organic matter removal efficiency of JWBO CW investigated by Brhanu (2007) was similar to that of the study done in USA: i.e., BOD₅ (93%) (USEPA, 1988); in Kenya: BOD₅ (98%), COD (96%) and TSS (85%) (Nyakango, 1999); in Northern Alabama: BOD₅ (85%) (Kathleen, 2000); and in Italy: COD (93%) and TSS (81%) (Puccie et al., 2000). The

higher removal of the planted treatment beds may be due to a combined biochemical reaction mechanism favored by plants, substrates, and microorganisms.

In addition to this, the media and macrophytes roots in SSF may provide a greater number of small surfaces, pores, and crevices which creates the opportunity for the availability of vast number of organic matter utilizing microorganisms adapted to the aerobic and anaerobic environment of wetland ecosystems which facilitate the organic matter removal process of CW more effective (USEP, 1993). According to Ayano (2013) demonstration on the performance efficiency of horizontal subsurface flow constructed wetland at deferent depth with the same media type (gravel, 8 – 16mm), wetland area and different hydraulic loading rate of 18L/m²/day and 36L/m²/day for depths 25cm and 50cm in planted and unplanted conditions, showed that no significant difference in removal of pollutants at the same HLR.

The removal of BOD₅ and TSS were not different between planted and unplanted beds. However, areal and volumetric rates for planted beds were significantly greater than the unplanted beds for TKN. Unplanted beds may be more anaerobic than planted beds to favor reducing bacteria. Garcia et al. (2004) reported that the removal of HSSFCW increased with decreasing depth and attributed high oxidation-reduction potential which is responsible for increasing nitrification. The result showed that constructed wetlands are successful in the removal of nutrients from domestic wastewater.

Heavy metal removal efficiency of HSSFCW

Many heavy metals are toxic to living systems. Recently there has been an increase in the river pollution trend in Addis Ababa and other cities, due to the discharge of untreated wastewater comes from the industries and municipal wastes. Constructed wetlands have a good potential for removal of heavy metals from wastewater (Sahu et al. 2014) According to Sahu (2014) report, the horizontal subsurface flow constructed wetland reduced the concentration of Hg, Cr, Fe, and Ni from the initial concentrations by 43%, 54%, 46% and 49% respectively. The potential heavy metal remediation of HSSFCW planted with *Phragmites australis* was investigated by Bahre (2013), and achieved higher removal efficiency of 99.33%, 93.67%, 89.24%, 96.14% and 98.33% respectively for Fe, Mn, Pb, Cu and Zn at hydraulic loading rate of 22Ld⁻¹ and hydraulic

retention time of 28th days. In the same regard, the unplanted unit showed removal efficiency of 98.43%, 91.66%, 85.01%, 90.70% and 85.19% for Fe, Mn, Pb, Cu, and Zn respectively at the same conditions. The result indicates that uptake on roots for Pb and Cu was higher than the uptakes by plant leaves and stems. The soil media-heavy metals accumulation also showed the highest adsorption capacity for the analyzed heavy metals from the planted and control systems. This demonstrates that horizontal subsurface flow constructed wetland planted with *Phragmites australis* and red ash gravel can

remove heavy metals from leachate. This result finding is similar to the reported metal removal efficiency of subsurface flow constructed planted with *S.globulosus* and *E. sexangularis* in treating leachates, which were 81.33% and 94.19% respectively for Cu and Pb; while 86.91% and 95.88% removal in *E. sexangularis* respectively for Cu and Pb (Mohamed et al. 2003). This finding also agrees with the result of Refidah (2002), who reported the removal efficiency of surface flow constructed planted with *S. sumantresisana* in treating leachate; which was 89%, 90%, and 89% respectively for Fe, Zn and Mn.

Table 3: Pollutant removal efficiency of HSSFCW in Ethiopia

Type of wastewater	Type media	Plant type	HLR (L/d)	HRT (day)	Removal efficiency (%)	Standards (EEPA,200)	Reference
Tannery	Clay (15cm)& gravel (45cm)	<i>C. alternifolius</i>	120	5	COD=64.8,BOD=67.5,TN=46,NH ₄ ⁺ =64.8	BOD=80%(200), COD=500, TSS=50,NH ₄ ⁺ =30 , TN=80% (60),TP=80%,(10)	Terfie and Assfaw (2014)
		<i>T. domingensis</i>			COD=56.6,BOD=66.7,TN=46.7,NH ₄ ⁺ =53		
		<i>B. aethiopicum</i>			COD=58,BOD=66,TN=58,NH ₄ ⁺ =80		
		<i>P. karka</i>			COD=81,BOD=64,TN=61,NH ₄ ⁺ =82.5		
		Unplanted			COD=38.4,BOD=64,TN=40.5,NH ₄ ⁺ =62.7 NO ₃ - N = 58.3 PO ₄ - P = 65.3		
		<i>P. Karaka</i>			NO ₃ - N = 56.4 PO ₄ - P = 84		
Domestic	Gravel (20–30mm)	<i>P. Cyprus</i>	26	7	NO ₃ - N = 36.1 PO ₄ - P = 50.2		Kassa and Mengistou (2014)
		Unplanted			COD=89.4,BOD=97.8,TSS=83.9,TN=53.9, NH ₄ ⁺ =24.8,NO ₃ ⁻ = 82.4, TP=16.5, PO ₄ ³⁻ =22.3		
		<i>C. papyrus</i>			COD=87.3,BOD=97.7,TSS=82.3,TN=54.8, NH ₄ ⁺ =24.6,NO ₃ ⁻ =78, TP=12.5, PO ₄ ³⁻ =16.2		
Domestic	Gravel (40–80mm) (20–30mm)	<i>C. alternifolia</i>	17.7	2.16	COD=89.6,BOD=98.1,TSS=83.2,TN=57,N H ₄ ⁺ =23,NO ₃ =81,TP=18.1, PO ₄ ³⁻ =23.4		Genet (2007)
		<i>P. canariensis</i>			BOD5=82,TSS=78.3,TN=27		
		<i>P. australis</i>			BOD5=82,TSS=78.3 TN=27		
Domestic	Gravel (8–16mm)	Unplanted	18	6			Ayano (2013)
			18	6			

The tannery wastewater analysis showed that the total chromium was reduced up to 99.3% for an inlet average Cr loading rate of 40mg/L (Amenu, 2015), similar with Terfie and Assfaw (2014) reported value of total chromium in HSSFCW beds. The plant part analysis of the accumulation of Cr showed similar results, more Cr was accumulated in root parts of the plants than the shoot. This indicates that constructed wetland is a cost-effective and environmentally friendly

treatment method in removal of not only organic matters, nutrients, and pathogens, but also heavy metals, and hence it can be used as an alternative treatment method for developing countries, tannery wastewater (Terfie and Assfaw, 2014). This may be due to chemical precipitation and sorption of metals on substrate media. Heavy metals in plant tissues and substrate media: The biological processes for metal removal in wetlands are plant uptake and adsorption on the substrate media.

Table 4: Heavy metal removal efficiency of HSSFCW in Ethiopia

Type of WW	Type media	Plant type	HLR (L/d)	HRT (day)	Removal efficiency (%)	Standards (EEPA,200)	Reference
Leachate	red ash gravel (15-25mm)	<i>P. australis</i>	22	28	Fe=99.33,Mn=93.67,Pb=89.24,Cu=96.14, Zn= 98.33		Bahre (2013)
Tannery	Clay (15cm)& gravel (45cm)	Unplanted	120	5	Fe=98.43,Mn=91.66,Pb=85.01,Cu=90.7, Zn= 85.19	Pb=0.5,Ni=2,Cu=2,Zn=5,Cr=2, Hg=0.001	Terfie and Asfaw (2014)
		<i>C. alternifolius</i>			Cr =35.84		
		<i>T. domingensis</i>			Cr =48.68		
		<i>B. aerthiopium</i>			Cr =26.96		
		<i>P. karka</i>			Cr =30.26		
		Unplanted			Cr =59.6 for Clay, 38.15 for gravel		
Synthetic			48.6	9	Cr=51%,Ni=47%, Fe=45%,Hg=43%		Sahu (2014)

HLR=hydraulic loading rate, HRT=hydraulic retention time, metal Standard limit conc. in mg/L

The Pb and Cu uptake ability *P. australis* by its roots may be due to the localized properties of the root, mainly predominated rhizofiltration mechanisms to accumulate heavy metals (Zhu et al. 1999). Similarly, Vymazal (1995) reported that plants can accumulate higher concentrations of metals in their roots. This may be due to the slow mobility of metal transport from the root to shoot (Kadlec and Wallace 2009). In the same case, substrate media is also one of the important factors for the removal of heavy metals. Figure 4 indicates that the role of substrate media for Pb and Cu removal from leachate. However, the retention time and the type of media affect the

treatment of wetlands (Knox et al. 2004). Media provides a viable condition for maximum removal of pollutants due to its diverse treatment mechanisms including sedimentation, adsorption, precipitation and microbial interaction (USEPA 1993). In general, the control HSSFCW showed the higher removal efficiency of Pb and Cu than the planted wetland. A similar finding was observed in the removal of chromium from Terfie and Asfaw (2014), indicates the clearly fate of total chromium in the horizontal subsurface flow constructed wetland. Whereas Kassa and Mengistou (2014) investigated the fate of total phosphorus is under question mark.

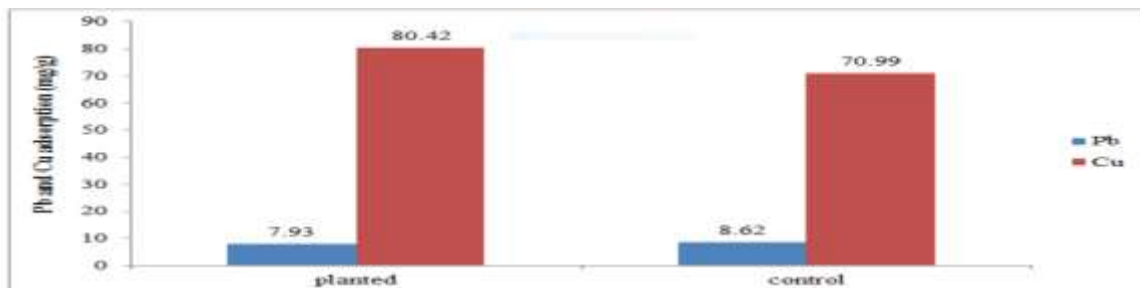


Figure 4: Pb and Cu adsorption in planted and control CW beds (substrate media, red ash gravel)

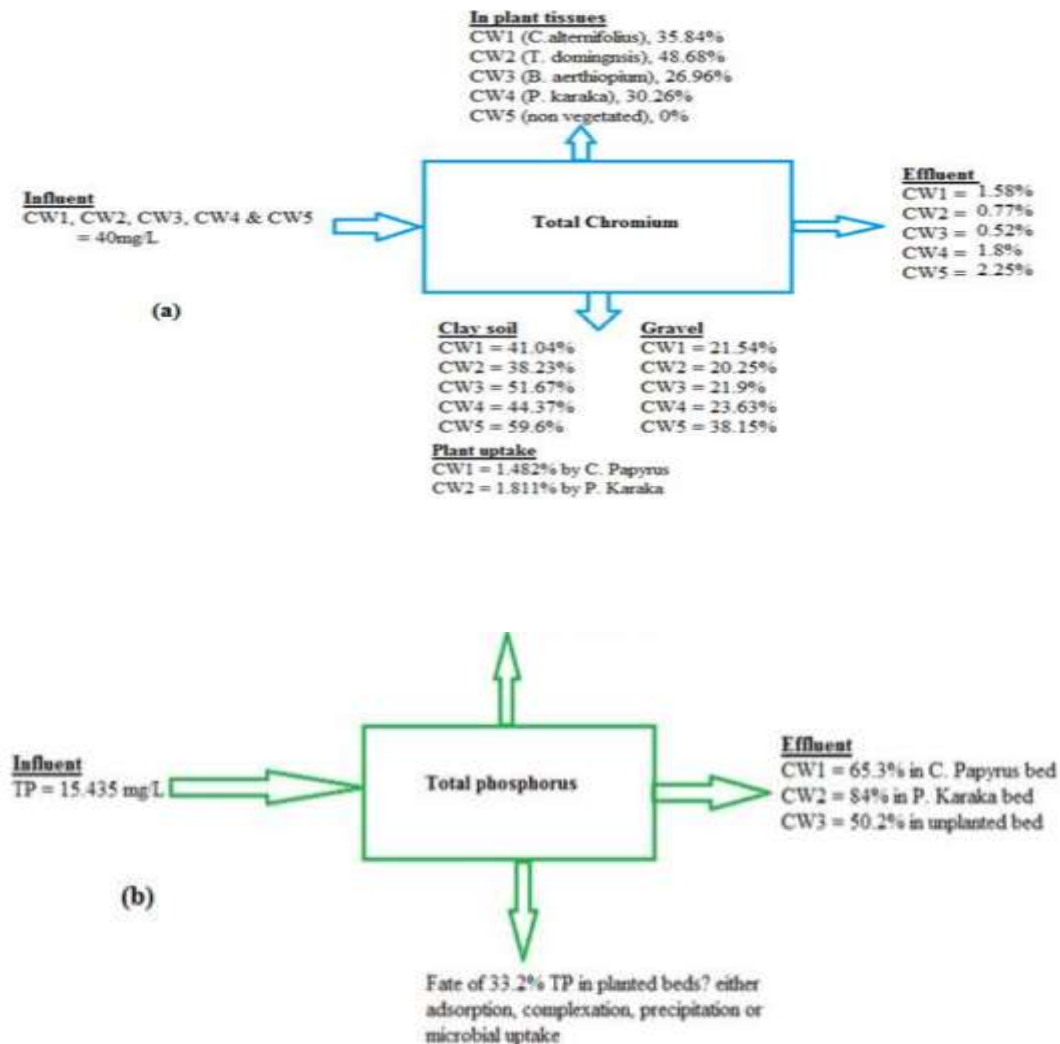


Figure 5: Mass balance of chromium and (b) mass balance of TP in HSSFCWs

However, the removal efficiency of heavy metals is dependent on the HRT, flow rate (Q) and pH. Sahu (2014), determined the effect of HRT on the reduction of different heavy metals (fig.). The maximum removal efficiency was observed at 9th days of treatment for Cr (51%), Ni (47%), Fe (45%) and Hg (43%). The treatment efficiency was increased as HRT increases from 1 to 7 days (fig.) at a flow rate (8cm³/min). The maximum removal of Cr (54%), Ni (49%), Fe (46%), and Hg (43%) were achieved at 8cm³/min flow rate.

Factors affecting the performance of constructed wetlands

Temperature: The microbial nitrification and denitrification activities can decreased considerably at water temperatures below 15oC or above 30oC, and most microbial communities for nitrogen removal function at temperatures greater than 15oC (Kuschek et al 2003) Literature revealed that

the activity of denitrifying bacteria in constructed wetland sediments is generally more robust in spring and summer than autumn and winter (83), and the overall removal rate of nitrate is higher in summer than in winter (Van Oostrom and Russell 1994) . De-nitrification is commonly believed to cease at temperatures below 15oC, but some studies have demonstrated de-nitrification activity at 14oC or lower temperatures. (Richardson et al.2004) Vymazal (2007) reported that the optimum temperature range for nitrification is 30 – 40oC in soils and the optimal ammonification is carried out at 40 – 60oC at the optimal pH between 6.5 and 8.5. At low temperature, nitrification is insufficient to prevent a net increase in ammonia concentration due to ammonification (Akratos et al. 2007).

Types of plant species: Plant species Plants used in constructed wetlands play a major role by

absorbing nutrients from wastewater. Some of the most important plant species ability for nutrient absorbing ability are summarized in Table 5.

Table 5: Nutrient absorption capacity of macrophytes (Brix, 1994)

Media type	Absorption capacity(Kg/ha/yr)	
	N	P
Cyperus alternifolius	1100	50
Typha latifolia	1000	180
Eichornia crassipes	2400	350
Pistia stratiotes	900	40
Potamogeton pectinatus	500	40
Certophyium demersum	100	10

Wetland plants, they often grow in gravel beds to stimulate uptake and create suitable conditions for the oxidation of the substrate, thereby improving the ability of the system to treat the wastewater (Njanu and Mlay 2000).

Several studies have shown that plants enhance treatment efficiency by providing a favorable environment for the development of microbial populations and by oxygenating the system. The roots of macrophytes provide surface areas for microbial growth and aerobic zones in constructed wetlands. In general, the main role of macrophytes in constructed wetlands is to promote microbial growth with the media surfaces, and to assist the permeation velocity of the wastewater for pollutant treatment efficiency. The nitrogen removal in constructed wetlands depends upon system design, environmental chemistry (roots, plants, water and sediments), plant uptake, available carbon and material type. The mean removal efficiency of the constructed wetland with planted (reeds) and unplanted during the three months of warm and cold study periods. In general, proper performance and high removal at the first treatment unit (septic tank) increases the efficiency of the treatment plant (Farzadkia et al. 2015). Vegetation and HRT: The TSS removal efficiency of planted and unplanted constructed wetland at different HRT was significantly different. The initial TSS concentration was 106 mg/L. Some while, after treatment under CW it was reduced to 35.4 and 19.7 mg/L at 2 and 4 days HRT with removal efficiency of 66.7% and 81.5% respectively in the vegetated one. Whereas, for the unplanted CW, TSS was reduced

to 62.3 and 49.8 mg/L for 2 and 4 days HRT with total removal efficiency of 41.5% and 53.2% respectively. The planted CW had higher in TSS removal than the unplanted one (fig. 6). The increase of HRT resulted in better TSS removal efficiency even for the unvegetated CW. The efficiency of BOD5 removal was 52% and 73.4% at HRT of 2 and 4 days in the planted beds. Constructed wetland without plantation removed only 20 – 35% BOD5 from the influent. Constructed wetland planted with *Canna indica* L. gave higher BOD5 removal efficiency than on – vegetation CW. The BOD5 removal also increased at higher HRT (i.e., almost half BOD5 removed at 4 days HRT) than shorter HRT (i.e. 2 days HRT). TKN removal in the vegetation CW also gave the maximum removal efficiency than the unvegetated CW. this removal efficiency of TKN may be associated with the addition of plant activity. CW planted with *Canna indica* L. removed TKN for 45.3% for 2 days HRT and 69.6% for 4 days HRT. TKN removal efficiency had increased at increasing HRT (Panrare et al., 2015). This TKN removal of the CW technique may be due to volatilization, plant uptake and bacterial assimilation (Vymazal, 2007). The vegetated CW at 4 HRT also gave the highest phosphate removal efficiency (77.7%). This phosphate removal in CW could be normally by plant and bacterial uptake, adsorption at the media and sedimentation. The effect of vegetation and HRT on the performance efficiency of constructed wetlands is indicated.

Media type: The level of permeability and hydraulic conductivity of the media is very influential on the retention time of wastewater, in which the retention time is enough to give a chance to contact between microorganisms in wastewater and oxygen released by plant roots. The main function of the media in the constructed wetland are places for plants to grow, as helping the absorption odor of the gases of biodegradation. While other role in the transformation process is a chemical, material storage nutrient required by plants (Dadan et al. 2016). The performance of subsurface flow constructed wetland based can be shown in Table 3 below.

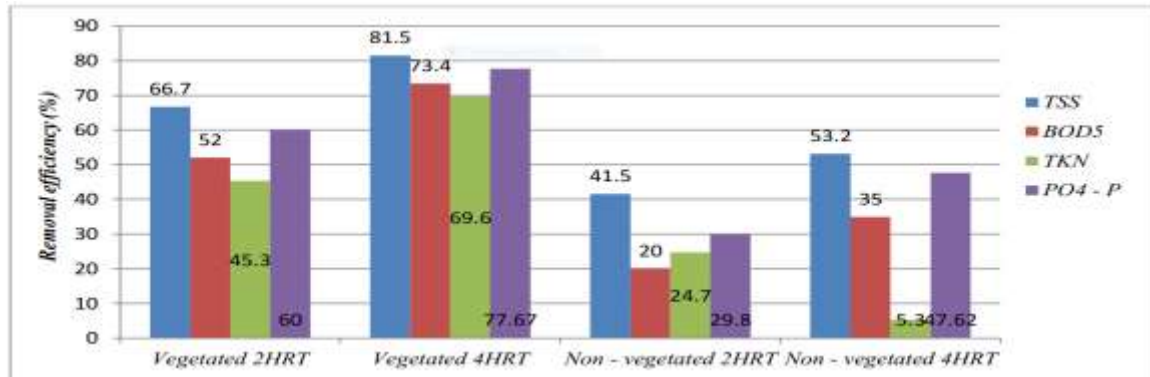


Figure 6: Effect of vegetation and HRT on pollutant removal efficiency of CW

Table6: Performance of SSFCW media (Khatuddin, 2003)

Media type	Percentage removal efficiency (%)		
	BOD	SS	Coliforms
Gravel	55-96	51-98	99
Soil	62-85	49-85	-
Sand	96	94	100
Clay	92	91	-

The removal of nutrients from constructed wetlands are also dependent on the media types. The accumulation of total nitrogen and phosphorus in the constructed wetland media was also investigated by Tilak et al. (2016).

Microorganisms: Preferably are heterotrophic aerobic microorganisms due to faster processing ability than anaerobic types. The oxygen content in the media will be supplied by plant roots, which is a byproduct of the process of photosynthesis with the help of sunlight (Dadan et al. 2016).

Other factors: Other important factors are wetland depth, pH, and DO. The nitrification and denitrification process depend upon water pH, the presence or depletion of dissolved oxygen, hydraulic loading rate, and the hydrological period of the wetland. At low DO concentration, nitrification occurs in the aerobic zone but denitrification occurs in the anoxic zone (Kadlec and Knight, 1996, Vymazal, 1999).

The biofilm may improve the denitrification; because of algae provide a desirable carbon source for denitrifiers (Marinelarena and Di Giorgi, 2001). In general, to maintain and improve nitrogen removal and water quality in constructed wetlands, attention should be given to factors that promote the growth rate of macrophytes and bacterial, such as planting depth, harvesting time, optimization of temperature, pH, DO and HRT.

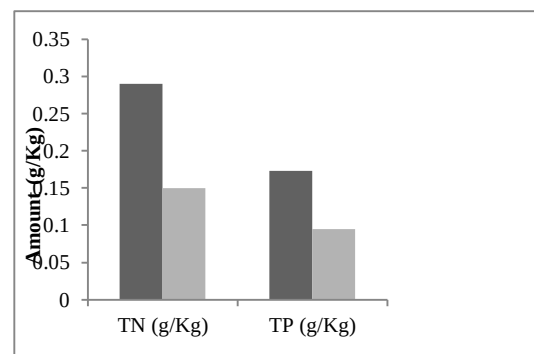


Figure 7: Nutrient accumulations in constructed wetland sand media

Conclusion

This review shows that, the strategies of treating domestic and municipal wastewaters become common in rural and urban areas using constructed wetland technologies. Besides this, constructed wetlands are accepted as a reliable wastewater technology as post-treatment of effluents. Because, they are low cost, easily operated and maintained and have a strong perspective for application in developing countries. The review also reveal the promising natural technology of subsurface horizontal flow phytoremediation in the treatment of municipal or industrial wastewater. The HSSFCW treatment system and abatement efficiencies (BOD5, COD, TSS, TN, NH4 -N, PO43) in Ethiopia is found to be meagre as compared from the global achievement and from the WHO (1989) standard. The important role of CWs, phytoremediation of wastewater in climate change mitigation is showed in this review. Moreover, the effectiveness of horizontal subsurface flow constructed wetland to abate key contaminants from wastewater was reviewed.

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