International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133; Print ISSN: 2664-7125; Impact Factor: RJIF 5.28
Received: 14-03-2020; Accepted: 15-04-2020; Published: 20-06-2020
Volume 2; Issue 2; 2020; Page No. 41-48

Constructed wetlands: A possible solution for municipal wastewater treatment: A review

Amit Biswas
Research Fellow, Agricultural & Food Engineering Department, IIT Kharagpur, West Bengal, India

Abstract

Crucial state of total available fresh water resources makes non-traditional water resources useful to meet incomparable global water demand. In this case, treated municipal waste water can serve as a valuable resource to reduce the demand of fresh water in number of countries. Over the years, several technologies, e.g., constructed wetlands, waste stabilisation pond, vermi-filtration, membrane bio-reactor, up-flow anaerobic sludge blanket reactor have been developed to treat different types of waste water. The present study focussed on the performance of constructed wetland (CW) for removal of different physical, chemical and biological contaminants to make the wastewater suitable for irrigation purpose. The investigation revealed that both surface and sub-surface flow wetlands were used for municipal wastewaters. Within sub-surface flow, both vertical and horizontal flow systems were designed. In addition, the applications of hybrid CWs for municipal wastewaters were also documented in this review article. The worldwide application of CWs suggested that CWs alone performed better for removal of physical (turbidity, total suspended solids) and some chemical impurities than biological impurities from municipal wastewater.

Keywords: constructed wetland, horizontal flow systems, municipal wastewater, sub-surface flow wetland, total suspended solids, turbidity

1. Introduction

The total volume of available water on the earth is about 1.39 × 10^9 km^3 with 97.50% salty and 2.50% fresh ones. Out of the total freshwater volume, about 30% is groundwater and about 70% is in the form of ice and permanent snow cover in the mountainous, Antarctic and Arctic regions, water in lakes and rivers, atmospheric water, soil moisture and biological water. Out of the total freshwater resources withdrawn (3,906.70 km^3/yr.), about 11% is used for municipal purposes, respectively (FAO-AQUASTAT 2015) [12]. According to the 2011 census report the world population is about 7 billion and is projected to be about 9.50 billion by the year 2050. Therefore, the rapid population growth in the world is obvious in the future. Such kind of population growth, rapid urbanization, industrialisation and advanced lifestyles will lead to an unprecedented increase in freshwater demand in the future. Therefore, alternative water resources will be very much essential to satisfy the unparalleled freshwater demand. Agriculture is the largest water user worldwide and it is expected that its share would decrease in future to meet the water demands of other sectors. On the other hand, rapid urbanization, indiscriminate use of freshwater will lead to a hasty increase in municipal wastewater. In such a critical situation, treated municipal wastewater can play an important role as an alternative source of water particularly for irrigation. The use of properly treated water may be economically feasible for the poor farmers also.

Municipal wastewater can be defined as the combination of wastewater coming from household connections, institutions and small enterprises. Sometimes, surface water and storm-water are also considered under municipal wastewater category (Al-Sarawy *et al*. 2001; Ismail *et al*. 2012) [4, 16]. Globally, the total volume of generated municipal waste-water is about 85.85% of the volume of total waste-water produced per year (FAO-AQUASTAT 2015) [12]. According to FAO-AQUASTAT (2015) [12], the worldwide treated municipal wastewater is about 155.41 km^3/yr (about 51.94% of globally produced). About 2%, 1%, 0.0%, 0.0%, 6% and 0.08% of the total volume of produced municipal wastewater is used for irrigation under non-treated condition in Asia, Africa, Europe, Oceania, North America and South America respectively whereas, about 4%, 7%, 1%, 14%, 2% and 6% of the total treated water is used for irrigation in these continents respectively (FAO-AQUASTAT 2015) [12]. The use of untreated waste water for irrigation may results in serious health consequences and its proper treatment is necessary to protect both health and environment. Thus, proper treatment and management of municipal wastewater are required to meet the exceptional freshwater demand of 9830 km^3/yr by 2025 in the world.

For the treatment of municipal wastewater, different technologies are practiced in the different parts of the world. These different technologies are activated sludge process (Tandukar *et al*. 2007) [38], coagulation & flocculation process (Ukiwel *et al*. 2014), waste stabilisation pond (Naddafi *et al*. 2009) [30], vermi-filtration (Manyuchi *et al*. 2013) [25], membrane bio-reactor (Zhang *et al*. 2010), up-flow anaerobic sludge blanket reactor (Kasaudhan *et al*. 2013) [19], constructed wetlands (Merlin *et al*. 2002; Vymazal 2005; Abou-Elela *et al*. 2012) [27, 8, 2] etc. The performances and intricacies of these technologies in removing different contaminants vary from one to another. Among these different technologies, constructed wetlands (CWs) are well structured engineered systems that use the natural processes involving soils, different wetland vegetations and their associated microbes to aid in reclamation of wastewater. This method can take the benefit of many of the same processes that take place in natural wetlands, but do so within a more controlled atmosphere.

With this background, the present study aims to review the performance of CWs for making municipal wastewater suitable for irrigation purpose based on the removal of different physical, chemical and biological impurities from municipal wastewater.

2. Materials and Methods

2.1 Physical parameters

The principal physical properties are turbidity, colour, total suspended solids (TSS) and odour. Turbidity is an expression of the optical property that causes scattering and absorption of light by molecules and particles rather than transmission in straight lines through a water sample. It is caused by suspended mineral matter, finely divided organic and inorganic matter, soluble coloured organic compounds, phytoplankton, and zooplankton. It is generally measured by an optical instrument called a turbid meter and expressed by Nephelometric Turbidity Units (NTU). Colour of municipal wastewater generally differs from the true colour of the water due to presence of turbidity. True colour is obtained after removal of turbidity. The TSS includes all suspended particles which cannot pass through a filter. The TSS is measured by spectrophotometer (AbdEL-rahman *et al*. 2015) [1]. It is generally expressed by mg/l. Another common problem with municipal wastewater treatment and application is odour. It is generally characterized by its intensity and hedonic tone (the pleasantness or nastiness). Offensiveness of odour combines intensity and hedonic tone as well as duration and frequency.

2.2 Chemical and Biological parameters

The vital chemical constituents are: hydrogen ion activity (pH), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonium nitrogen (NH_4-N), nitrate (NO_3-N), total nitrogen (TN), ortho-phosphate, total phosphorus (TP), calcium (Ca), sodium (Na), magnesium (Mg), iron (Fe), heavy metals like cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), lead (Pb), zinc (Zn), arsenic (As), mercury (Hg) etc., chloride, sulphate, carbonate, bi-carbonate, sodium adsorption ratio (SAR), electrical conductivity (EC) etc. (Fountoulakis *et al*., 2009; Alobaidy *et al*., 2010) [13, 3]. The principal biological impurities of wastewater include fecal coliform (FC), total coliform (TC), fecal streptococci (FS), helminth egg (HE) etc. (Nasr *et al*., 2008; Kadam *et al*., 2009) [31, 18].

2.3 Irrigation Standard Quality for physical, chemical and biological parameters

The allowable limits of physical, chemical and biological properties of wastewater for irrigation purpose are discussed in this section. The country-wide variations of standard limit for TSS and turbidity are shown in Fig. 1 and 2 respectively along with the guidelines provided by United States Environmental Protection Agency (USEPA) and Alberta Environment (AE). The standard level of different chemical and biological impurities provided by United States Environmental Protection Agency (USEPA) and Food and Agricultural Organisation (FAO) are presented in Table 1.

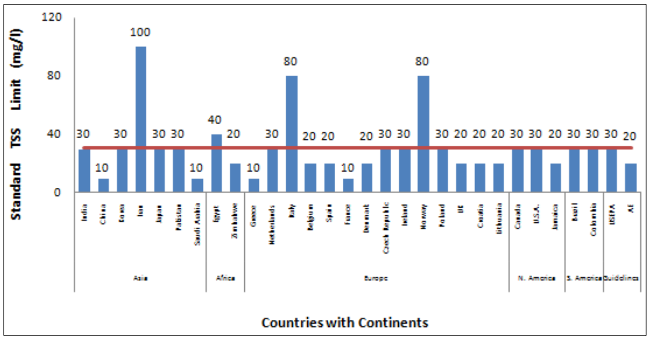

Fig 1: Standard limits of TSS (mg/l) in water for Irrigation purpose

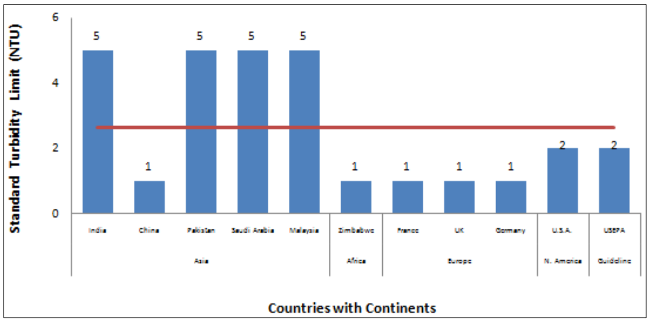

Fig 2: Standard limits of Turbidity (NTU) in water for Irrigation purpose

Table 1: Water quality standard according to USEPA and FAO guidelines

Serial No.	Chemical and Biological Parameters	Unit	Guidelines	
			USEPA	FAO
1.	pH	*	6.50-8.40	6.50-8.50
2.	TDS	mg/l	<450	2000
3.	BOD	mg/l	10	*
4.	COD	mg/l	*	*
5.	NH_4-N	mg/l	*	0-5
6.	Nitrite	mg/l	*	*
7.	Nitrate (NO_3-N)	mg/l	<5	0-10
8.	Total Nitrogen (TN)	mg/l	*	30
9.	Phosphate-P	mg/l	*	0-2
10.	Total Phosphorus (TP)	mg/l	*	*
11.	Potassium (K)	mg/l	*	0-2
12.	Calcium (Ca)	mg/l	*	400
13.	Magnesium (Mg)	mg/l	*	60
14.	Sodium (Na)	meq/l	<3	900

15.	Manganese (Mn)	mg/l	0.20	0.20
16.	Iron (Fe)	mg/l	5.00	5.00
17.	Cadmium (Cd)	mg/l	0.01	0.01
18.	Cromium (Cr)	mg/l	0.10	0.10
19.	Zinc (Zn)	mg/l	2.00	*
20.	Lead (Pb)	mg/l	5.00	2.00
21.	Nickel (Ni)	mg/l	0.20	5.00
22.	Boron (B)	mg/l	0.75	0-2
23.	Chloride	mg/l	<70	1100
24.	Sulphate (SO_4)	mg/l	*	1000
25	Carbonate (CO_3)	mg/l	*	0-100
26.	Bicarbonate (HCO_3)	mg/l	<150	600
27.	SAR	*	<3	15
28.	Electrical Conductivity	dS/m	<0.70	3.00
29.	Copper (Cu)	mg/l	0.20	0.10
30.	Aluminium (Al)	mg/l	5.00	*
31.	Cobalt	mg/l	0.05	0.05
32.	Fluoride	mg/l	1.00	*
33.	Arsenic	mg/l	0.10	*
34.	Beryllium	mg/l	0.10	*
35.	Molybdenum	mg/l	0.01	*
36.	Vanadium	mg/l	0.10	*
37.	Selenium	mg/l	0.02	*
38.	Lithium	mg/l	2.50	*
39.	Fecal Coliform	-	23/100 ml	< 200/100 ml

* indicates data unavailability

2.4 Constructed Wetlands (CWs)

General Information:

Wetlands are 'innate filters of water' (Hammer and Bastian 1989). Wetland treatment process diminishes impurities like TSS, turbidity, organic matter, inorganic matter, trace organics and pathogens from the water. The capability of wetland to renovate and accumulate organic matters and nutrients makes this technology "the natural kidneys of the land" (Mitsch and Gosselink 1993) [28].

The CWs were primarily used for secondary treatment of municipal wastewaters and these systems were capable of eliminating organics and suspended solids significantly. The CWs can be categorized according to different criteria such as flow path in sub-surface wetlands (such as vertical and horizontal), hydrology (like open surface and sub-surface flow) and macrophytic growth (such as free floating, emergent, submerged) etc. (Vymazal 2014) [8]. Sometimes hybrid CWs (combination of different types of CWs) were also utilized instead of a particular type for successful treatment of wastewater.

Working Principle

Treatment of wastewater by this method is generally accomplished through biological processes (like microbial metabolic activity and plant uptake) and physicochemical processes (like precipitation, adsorption and sedimentation at the root-sediment, water sediment and plant-water interfaces) (Watson *et al*. 1989) [47]. The treatment process through this technology is shown by flow diagram in Fig 3.

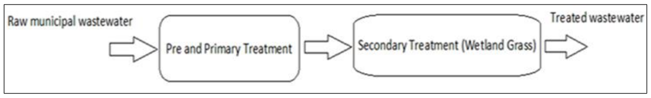

Fig 3: Flow diagram of CW treatment processes

3. Results and Discussions

3.1 Removal of physical impurities from municipal wastewater through CWs

Gersberg *et al*. (1986) investigated the performance of artificial wetland for treatment of primary municipal wastewaters considering three types of aquatic plants (bulrush, common reed and cattail). The results indicated that the performance of all vegetated beds was satisfactory as the mean TSS concentration in raw wastewater reduced from 58.10 mg/l to 3.70, 7.90 and 5.50 mg/l for those plants respectively. The best TSS removal efficiency (about 93.63%) was obtained through bulrushes at the hydraulic application rate of 4.70 cm/d. at this application rate, the area requirement of CWs for daily treatment of one million gallons was reported as about 20 acres. The performance of non-vegetated bed was also very good as it reduced the TSS value upto 5.60 mg/l. There was no significant difference between the performances of vegetated and non-vegetated bed. This phenomenon suggested that TSS elimination took place almost completely because of only physical techniques (like sedimentation, filtration) instead of any biological process associated with the microbes. Schierup *et al*. (1990) [35] reviewed the treatment performances of Danish CWs. Most of those were of horizontal subsurface flow type. Some beds were planted with *Phragmites australis* and some utilized the both *Phragmites australis* and *Typha latifolia*. Generally, local soil was used in those beds. But, some systems used soil mixtures to improve the hydraulic conductivity of the media. For dealing with low hydraulic conductivity, the cross-sectional area required for water infiltration was changed to as large as possible (for a given surface area). The overall performance of those systems is shown in Fig 4. The removal efficiency was more than 75% for most of the systems and the performance level usually enhanced with inlet concentrations. The research work suggested the necessity of mechanical pre-treatment of raw wastewater prior to the application to the reed bed. Cooper (1999) [7] used vertical flow (VF)-horizontal flow (HF) system which was comprised of six and three vertical beds at 1st and 2nd stage respectively and one horizontal bed for each of 3rd and 4th stage respectively. Vertical beds (8 m^2 for each) at 1st stage were planted with *Phragmites australis* whereas at 2nd stage these (5 m^2 for each) were planted with *Phragmites australis*, *Schoenoplectus lacustris* and *Iris pseudacorus*. Horizontal bed (8 m^2) at 3rd stage was with *Iris pseudacorus* while at the last stage it (20 m^2) contained *Schoenoplectus lacustris*, *Sparganium erectum* and *Acoru calamus*. TSS concentration was achieved as 53, 17, 11 and 9 mg/l at 1st, 2nd, 3rd and last stages respectively. Ultimately, about 95.27% TSS removal efficiency (Fig. 4) was obtained though this experiment. O'Hogain (2003) [32] also used VF-HF combined system which was comprised of four VF beds (total 64 m^2), two VF beds (total 60 m^2) and one HF (60 m^2) bed at 1st, 2nd and 3rd stage respectively. These filtration beds were shown highly effective in this study in term of TSS removal efficiency (98.11%) (Fig 4). The study recommended the system's working capability under the overloaded inflow situations. Water distribution procedure to the primary vertical beds was observed as reasonable while that on the secondary beds was not. In the study of Solano *et al*. (2004), cattail and reed were utilized with two different hydraulic application rates (150 and 75 mm/d) for two different HRTs (1.50 and 3 d). The performance of sub-surface flow CW was found excellent (93.48% TSS removal efficiency as shown in Fig. 4) for those beds having comparatively low hydraulic application rate (75 mm/d) and long HRT (3 d). The experiment showed the improvement of the system performance with the increasing of HRT. But, more tests with variable HRTs were suggested to ensure the overall performance of the system. No seasonal variation was observed in case of TSS removal, except in winter. During winter, relatively lower TSS removal performance was noticed. No significant difference between the TSS removal efficiencies obtained for same season of two years indicated that the elimination was entirely because of physical procedures (like filtration, sedimentation) instead of microbial processes. The incorporation of a pre-treatment step in the system was suggested to remove different floatable materials, grit etc. from raw wastewater and avoid unnecessary blockage of the system. Tayade *et al*. (2005) [39] also worked with sub-surface flow CWs (with two beds). Each of two beds was constructed as 2 m long, 1 m wide and 0.30 m deep. Bed 1 was planted with *Pennisetum purpureum* and *Typha latifolia* whereas bed 2 used *Canna indica* and *Cyperus spp.* In this research work, CW was constructed with one inlet chamber (with crushed bricks and sand), one treatment zone (with crushed bricks for upper layer, sand for middle layer and stones for lower layer) and one outlet zone (with three apertures). Hydraulic loading rate (HLR) and hydraulic retention time (HRT) for both the beds was 0.2614 m3/(m2/d) and 1.14 d respectively. Mean TSS removal efficiency was obtained as 83% (Influent: 144 mg/l, Effluent: 25 mg/l) and 75% (Influent: 152 mg/l, Effluent: 38 mg/l) from bed 1 and bed 2 respectively. The overall TSS removal efficiency is presented in Fig 4. This method was appreciated for wastewater treatment in rural areas where lands were easily available. Jozwiakowski (2007) evaluated the performance of single stage vertical-flow reed bed treatment system. The twelve years' research experience showed that TSS removal efficiency varied from 47% to 84% with mean removal efficiency of 59.25% (Fig 4). The study concluded that the performance of the system could be improved through yearly cutting and removal of reeds from vegetated bed. Morari *et al*. (2009) [29] used vertical flow CWs (VF CWs) with *Typha latifolia* and *Phragmites australis* for treatment of municipal wastewater. The seasonal variation of VF CWs was observed in this research work. Highest efficiency was obtained in summer month because of higher ET value. The study concluded that the treated water could not be used effectively for irrigation purpose because of poor performance of TSS removal (59.25% mean efficiency over 2 years) (Fig 4). They suggested the requirement of efficient pre-cleaning systems or innovative integrated systems for improving the performance of wetlands. Sharma *et al*. (2011) [36] studied on the horizontal sub-surface flow (HSSF) CWs for municipal wastewater treatment. According to the study, TSS of raw wastewater was reported as 257 mg/l and turbidity varied from 54.50 to 64.30 NTU. The highest turbidity level in the raw wastewater was achieved during the monsoon period (June-October) because of more volume of water flow and the presence of suspended matters, colloidal substances in the run-off. The treated effluent contained 82 mg/l TSS (68.09% removal efficiency as shown in Fig 4). This research work suggested that the proper treatment of raw wastewater could make it an invaluable alternative source for irrigation water. Hayder *et al*. (2015) investigated the performance of CW to treat wastewater of Lahore city. In this study, local plant (*Phragmites spp.*) was utilized in CW. The highest TSS removal efficiency through this method was achieved as 90% (Fig 4). The contaminant removal efficiency was enhanced with the increase in detention period and the best effluent quality was obtained at 5-days detention period. If raw wastewater was pre-settled, 4 days detention period was found as sufficient for significant TSS removal (82%). Rahi and Faisal (2019) studied the performance of horizontal sub-surface flow CW with coarse gravel (40-60 mm) to treat wastewater. In this study, local plant (*Phragmites Australia*) was utilized in CW. The highest TSS removal efficiency through this method was achieved as 73% (Fig 4). The best effluent quality was obtained at 2-days detention period.

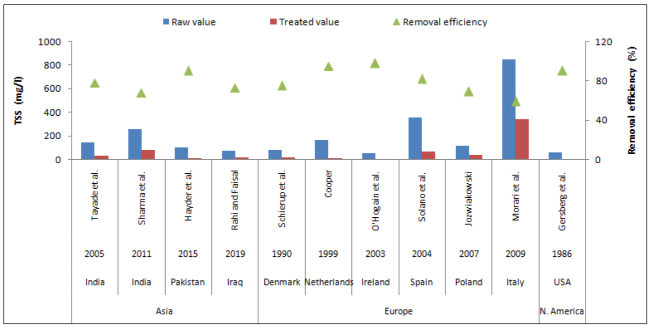

Fig 4: TSS concentration in raw and treated water along with TSS removal efficiency for CWs

3.2 Removal of chemical and biological impurities from municipal wastewater through CWs

Impurities like organic matters, inorganic compounds, heavy metals etc. are removed by this CW method through different treatment phases like sedimentation, filtration, vegetation uptake, adsorption, chemical precipitation and the collaboration of microbes (Watson *et al*. 1989) [47]. This method can effectively treat municipal wastewater having wide range of variations of inflow concentrations (Dipak *et al*., 2011) [11]. The principal advantages of this technology are: achievement of tertiary treatment standard with low cost, low maintenance cost, no electricity, no sludge handling problem, no odour and mosquito problem and provision as natural habitat for birds (Raval *et al*., 2015) [34]. But, the utilization of natural wetlands for treating wastewater is an old concept. Its large space requirement made its use critical. Therefore, the concept of artificial wetlands came for the treatment of wastewater. The first operation of such artificial wetland system was carried out in Germany in 1950. The use of horizontal sub-surface flow constructed wetlands (HSSF CWs) was started in 1960. After few years HSSF CW was modified as Root Zone treatment technology (Vymazal 2005) [8]. The root zone acts as biological filter. The root zone brings about the interactions of the Sun, air, water, soil, the roots of reed plants and microbes. CWs can efficiently remove chemical impurities like organic matters, heavy metals etc. as well as biological contaminants like bacteria, parasites, viruses from municipal wastewater (Kivaisi, 2001; Morari *et al*., 2009) [21, 29]. The most common artificial or constructed wetlands are horizontal subsurface flow type. Horizontal flow constructed wetlands (HF CWs) have capability to treat wastewater having low organic concentrations (Dipak *et al*., 2011) [11]. But vertical type is also getting admired recently (Vymazal 2005) [8]. Laouali *et al*. (1996) [23] used three-stage wetland for wastewater treatment and obtained very good result. But, the review on the provision of FWS stage at the end of the treatment process showed that it was good for better removal of nutrients whereas the removal efficiency of organics was slightly decreased because of algal growth. Laber *et al*. (2003) [22] worked on hybrid system consisting of HF (Horizontal Flow, 140 m^2) and VF (Vertical Flow, 120 m^2). The performance of such hybrid system was found to be excellent from the both chemical and biological parametric point of view (Fig 5-6, Table 2-3). Morari *et al*. (2009) [29] used two pilot-scale vertical flow constructed wetlands for municipal wastewater treatment. *Typha latifolia* was used in one wetland and the other was planted with *Phragmites australis*. Both wetlands performed well for removal of BOD, COD, N and K; whereas lower efficiencies were obtained for Na, Mg and TP. The results of the study indicated that the efficient pre-cleaning system was necessary for better performance of the wetlands. The worldwide review of the treatment performance of HF CWs revealed the satisfactory performance for removal of BOD_5 and COD; whereas for TN, TP, NH_4^+-N and NO_3^--N performance was not up to the expected level (Vymazal, 2001). According to Vymazal (2005), the depth of filtration bed of HF CWs should be generally 0.60-0.80 m to ensure the complete penetration of root of plants namely *Phragmites* and oxygenation of the entire bed. The roots and rhizomes of reeds and any type of wetland plants release sufficient amount of oxygen for aerobic degradation of oxygen consuming substance in the wastewater and for nitrification of the ammonia (Vymazal 2005). However, many other studies did not support this statement (Brix, 1990; Brix and Schierup, 1990) [35]. Those studies revealed the significant role of anoxic and anaerobic disintegration in HSF CWs. The results of such aerobic and anaerobic degradation in HSF CWs showed high organic removal efficiency (Vymazal 2005). But HF systems cannot produce fully nitrified effluents because of limited oxygen transfer capacity. On the other hand, VF systems are good for nitrification but cannot support de-nitrification. Therefore, VF and HF systems are combined sometimes to obtain better performance in terms of TN removal (Cooper, 1999, 2001; Vymazal, 2005) [9]. According to the study of O'Hogain (2003) [], VF-HF systems were effective for BOD_5, COD and TN removal except for phosphorus. Masi *et al*. (2002) [26] used hybrid wetlands and observed excellent performance for removal of BOD, COD, TN and TP. The satisfactory performances of HF-VF systems were also obtained from the study of Brix *et al*. (2003) for Denmark. The study of Mander *et al*. (2003) [24] was on a hybrid system which consisted of VF, HF and FWS stages. The combination of these three stages showed removal efficiency 88%, 65% and 72% for BOD_7, TN and TP respectively. According to Kipasika *et al*. (2014), fecal cloliform removal efficiency of CW was satisfactory while its treated effluent contained more *salmonella spp.* compared to maturation pond. Rahi and Faisal (2019) [33] studied the performance of horizontal sub-surface flow CW with coarse gravel (40-60 mm) to treat wastewater. In this study, local plant (*Phragmites Australia*) was utilized in CW. The highest BOD and phosphate removal efficiency through this method was achieved as 84 and 55% respectively (Fig 5). The best effluent quality was obtained at 2-days detention period.

According to Cueto (1993) [10], the average capital cost was $1.60 per gallon for wetland system; whereas for traditional method it was $5.59 per gallon. The significant difference between the operational and maintenance costs of those treatment techniques was observed. Vymazal (2002) [8] also studied on the associated economics of CWs and concluded that the operational and maintenance costs were significantly lower than advanced technologies. Therefore, CWs can be considered as feasible alternative to the traditional wastewater treatment techniques.

The performance of the CW for deduction of both chemical and biological impurities from municipal wastewater was evaluated and shown in Fig 5-6, and Table 2-3.

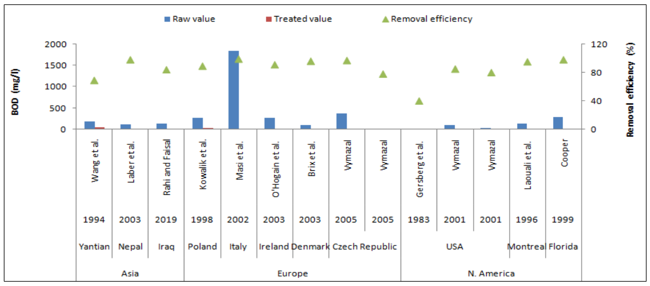

Fig 5: BOD concentration in raw and treated water along with removal efficiency for CWs

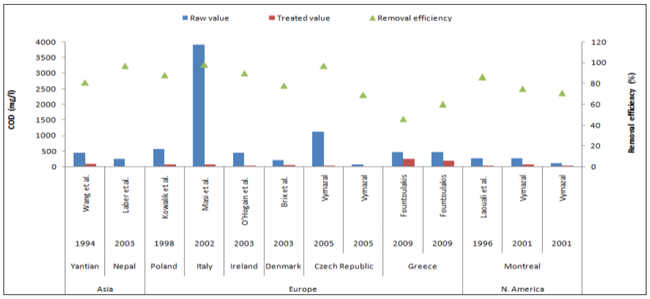

Fig 6: COD concentration in raw and treated water along with removal efficiency for CWs

Table 2: Performance of CW treatment method for removal of TDS, EC, *E. Coli* and FC

Parameters	References	Year	Treatment Methods	Country	Raw Value	Treated Value	Removal Performance
Total dissolved solids (TDS)	Kadam *et al*.	2009	India	CSF	226.40-270.60 mg l^{-1}	213.70-264.50 mg l^{-1}	2.25-5.61%
	Rahi & Faisal	2019	Iraq	Horizontal sub-surface flow CW	1565 mg l^{-1}	1551 mg l^{-1}	< 1%
Electrical conductivity (EC)	Kadam *et al*.	2009	India	CSF	335.80-404.20 dS m^{-1}	319.10-395.10 dS m^{-1}	< 1%
	Rahi & Faisal	2019	Iraq	Horizontal sub-surface flow CW	3.12 dS m^{-1}	3.10 dS m^{-1}	< 1%
E. Coli	Laouali *et al*.	1996	Hybrid System	Montreal	4.80*10^5 CFU/ 100 ml	190 CFU/ 100 ml	3.40 log
	Laber *et al*.	2003	HF-VF Hybrid System	Nepal	7.20 log CFU/ 100 ml	1.30 log CFU/ 100 ml	5.90 log
Fecal Coliform (FC)	Vymazal	2005	Horizontal flow CWs	USA	1.27*10^7 CFU/ 100 ml	9.96*10^5	92%
	Fountoulakis *et al*.	2009	CW	Greece	56.30*10^5 CFU/ 100 ml	5.80*10^5 CFU/ 100 ml	1.0 log
			Horizontal surface flow CW			0.30*10^5 CFU/ 100 ml	2.30 log
	Kadam *et al*.	2009	CSF	India	2.0*10^7 CFU/ 100 ml	3.10*10^4 CFU/ 100 ml	-
	Kipasika *et al*.	2014	CW	Tanzania	7400.14-8000.64 CFU/ 100 ml	3800.21-4100.07 CFU/ 100 ml	48.46-49.07%

CFU indicates colony-forming unit

Table 3: Performance of CW treatment method for removal of TC and FS

Parameters	References	Year	Treatment Methods	Country	Raw Value	Treated Value	Removal Performance
Total Coliform (TC)	Vymazal	2005	Horizontalflow CWs	Czech Republic	6.14 log	5.01 log	1.10 log
	Fountoulakis *et al*.	2009	CW	Greece	411.50*10^5 CFU/ 100 ml	20.40*10^5 CFU/ 100 ml	1.30 log
			Horizontalsurface flow CWs			2.60*10^5CFU/ 100 ml	2.20 log
	Kadam *et al*.	2009	CSF	India	3.50*10^8 CFU/ 100 ml	2.40*10^5 CFU/ 100 ml	-
Fecal Streptococci (FS)	Laouali *et al*.	1996	Hybrid System	Montreal	2.60*10^4	70	2.60 log
	Vymazal	2005	Horizontalflow CWs	Czech Republic	4.47 log	3.62 log	0.90 log
	Fountoulakis *et al*.	2009	CW	Greece	47.90*10^5 CFU/ 100 ml	6.00*10^5 CFU/ 100 ml	0.90 log
			Horizontalsurface flow CWs			0.40*10^5 CFU/ 100 ml	2.10 log

CFU indicates colony-forming unit

4. Conclusions

This literature survey was conducted with constructed wetland treatment technology for removal of several physical, chemical and biological impurities from municipal wastewater. Based on the review of this wastewater reclamation method, the following conclusions can be drawn.

- TSS removal efficiency was found to vary from 59 to 98%.
- BOD removal efficiency was found to vary from 40 to 99%.
- COD removal efficiency was found to vary from 46 to 98%.
- Average worldwide performance of CW for removal of biological contaminants was found as questionable.

Therefore, this survey revealed the worldwide satisfactory performance of constructed wetland for removal of physical and some chemical impurities. But, this study suggested some modern advanced technique (like ultraviolet radiation, chlorination) to be practiced with this economically viable constructed wetland system to meet biological standard for irrigation purpose.

5. References

1. AbdEL-rahman AM, AbdEL-halim A, AM Gad A, Hashem M. Assessment of waste stabilization ponds for the treatment of municipal wastewater in Upper Egypt. IOSRJEN. 2015; 5(1):10-18.
2. Abou-Elela Sohair I, Hellal SM. Municipal wastewater treatment using vertical flow constructed wetlands planted with Canna, Phragmites and Cyprus. Ecolog Eng. 2012; 47:209-213.
3. Alobaidy AHMJ, Al-Sameraiy MA, Kadhem AJ, Majeed AA. Evaluation of treated municipal wastewater quality for irrigation. Journal of Environmental Protection. 2010; 1(3):216.
4. Al-Sarawy A, El-Sherbiny F, Mels R. Coagulation and flocculation of domestic sewage with organic polyelectrolyte. J Alex Eng. 2001; 40(5):777-782.
5. Brix H. Gas exchange through the soil-atmosphere interphase and through dead culms of *Phragmites australis* in a constructed reed bed receiving domestic sewage. Water Res. 1990; 24:259-266.

6. Brix H, Arias C, Johansen NH. Experiments in a two-stage constructed wetland system: nitrification capacity and effects of recycling on nitrogen removal. In: Vymazal, J. (Ed.), Wetlands: Nutrients, Metals and Mass Cycling. Backhuys Publishers, Leiden, The Netherlands, 2003, pp. 237-258.
7. Brix H, Schierup HH. Soil oxygenation in constructed reed beds: the role of macrophyte and soil-atmosphere interface oxygen transport. In: Cooper, P.F., Findlater, B.C. (Eds.), Constructed Wetlands in Water Pollution Control. Pergamon Press, Oxford, UK, 1990, pp. 53-66.
8. Cooper PF. Nitrification and denitrification in hybrid constructed wetlands systems. In: Vymazal J (Ed.), Transformations on nutrients in natural and constructed wetlands. Backhuys Publishers, Leiden, The Netherlands, 1999, 257-270.
9. Cooper PF. Nitrification and denitrification in hybrid constructed wetlands systems. In: Vymazal J (Ed.), Transformations on nutrients in natural and constructed wetlands. Backhuys Publishers, Leiden, The Netherlands, 2001, 257-270.
10. Cueto AJ. Development of criteria for the design and construction of engineered aquatic treatment units in Texas. CRC Press: Boca Raton, FL, 1993.
11. Dipak S, Dubey A. Assessment and treatment of municipal wastewater of Indore city of India. Arch A Sci Res. 2011; 3(1):450-461.
12. FAO-AQUASTAT. Global information system on water and agriculture. 2015. http://www.fao.org/nr/water/aquastat/main/index.stm.
13. Fountoulakis MS, Terzakis S, Chatzinotas A, Brix H, Kalogerakis N, Manios T, *et al*. Pilot-scale comparison of constructed wetlands operated under high hydraulic loading rates and attached biofilm reactors for domestic wastewater treatment. Science of the total environment. 2009; 407(8):2996-3003.
14. Gersberg RM, Elkins BV, Lyon SR, Goldman CR. Role of aquatic plants in wastewater treatment by artificial wetlands. Water Res. 1986; 20(3):363-368.
15. Haydar S, Haider H, Nadeem O, Hussain G, Zahra S. Proposed model for wastewater treatment in Lahore using constructed wetlands. J Facul Eng Technol, 2015, 22(1).
16. Ismail IM, Fawzy AS, Abdel-Monem NM, Mahmoud MH, El-Halwany MA. Combined coagulation flocculation pre-treatment unit for municipal wastewater. J Adv Res. 2012; 3(4):331-336.
17. Jóźwiakowski K. The experience from twelve-year operation of reed bed treatment system with vertical flow. Pol J Environm Stud. 2007; 16(2A):519-615.
18. Kadam AM, Nemade PD, Oza GH, Shankar HS. Treatment of municipal wastewater using laterite-based constructed soil filter. Ecological Engineering. 2009; 35(7):1051-1061.
19. Kasaudhan GK, Mumtaz N, Raj V. Optimization of municipal wastewater treatment by UASB reactor and polising pond. Biolife. 2013; 1(4):200-207.
20. Kipasika HJ, Buza J, Lyimo B, Miller WA, Njau KN. Efficiency of a constructed wetland in removing microbial contaminants from pre-treated municipal wastewater. Physics and Chemistry of the Earth. 2014; 72-75:68-72.
21. Kivaisi AK. The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. Ecolog Eng. 2001; 16(4):545-560.
22. Laber J, Haberl R, Langergraber G. Treatment of hospital wastewater with a 2-stage constructed wetland system. In: Haberl, R., Langergraber, G. (Eds.), Achievments and Prospects of Phytoremediation in Europe. University of Natural Resources and Applied Life Sciences, Vienna, Austria, p. 85 (book of abstracts), 2003.
23. Laouali G, Dumont L, Radoux M, Vincent G. General design and performance of reed and emergent hydrophyte beds for domestic wastewater treatment in Qu´ebec, Canada. In: Proceedings of Fifth International Conference Wetland Systems for Water Pollution Control, IWA and Universit¨at f¨ur Bodenkultur, Vienna, (Chapter IX/5), 1996.
24. Mander U″, Teiter S, Lo˜hmus K, Mauring T, Nurk K, Augustin J, *et al*. Emission rates of N2O and CH4 in riparian alder forest and subsurface flow constructed wetland. In: Vymazal, J (Ed.), Wetlands: Nutrients, Metals and Mass Cycling. Backhuys Publishers, Leiden, The Netherlands, 2003, pp. 259-279.
25. Manyuchi MM, Kadzungura L, Boka S. Vermifiltration of Sewage Wastewater for Potential Use in Irrigation Purposes Using Eisenia fetida Earthworms. World Academy of Science, Engineering and Technology 78, 2013.
26. Masi F, Conte G, Martinuzzi N, Pucci B. Winery high organic content wastewaters treated by constructed wetlands in Mediterranean climate. In: Proceedings of Eighth International Conference Wetland Systems for Water Pollution Control, IWA and University of Dar es Salaam, 2002, pp. 274-282.
27. Merlin G, Pajean JL, Lissolo T. Performances of constructed wetlands for municipal wastewater treatment in rural mountainous area. Hydrobiologia. 2002; 469(1-3):87-98.
28. Mitsch WJ, Gosselink JG. Wetlands. second ed Wiley, New York, 1993, pp 722.
29. Morari F, Giardini L. Municipal wastewater treatment with vertical flow constructed wetlands for irrigation reuse. Ecolog Eng. 2009; 35(5):643-653.
30. Naddafi K, Hassanvand MS, Dehghanifard E, Faezi Razi D, Mostofi S, Kasaee N, *et al*. Performance evaluation of wastewater stabilization ponds in Arak-Iran. J Environ Health Sci Eng. 2009; 6:41-46.
31. Nasr FA, El-Ashmawy A, Eltaweel G, El-Shafai SA. Waste Stabilization Ponds for Wastewater Treatment and Reuse in Egypt. Environmental Sciences Division, Department of Water Pollution Research, 2007.
32. O’Hogain S. The design, operation and performance of a municipal hybrid reed bed treatment system. Water Sci Technol. 2003; 48(5):119-126.
33. Rahi MA, Faisal AAH. Using horizontal subsurface flow constructed wetland system in the treatment of municipal wastewater for agriculture purposes. IQ J Agr Scs. 2019; 50(3):1208-1217.
34. Raval AA, Desai PB. Root Zone Technology: Reviewing its Past and Present. Int J Curr Microbiol App Sci. 2015; 4(7):238-247.
35. Schierup HH, Brix H, Lorenzen B. Wastewater treatment in constructed reed beds in Denmark-State of the art.

Constructed wetlands in water pollution control, 1990, 495-504.

36. Sharma D, Dubey A. Assessment and treatment of municipal wastewater of Indore city of India. Archives of Applied Sci Res. 2011, 3(1):450-461.
37. Solano ML, Soriano P, Ciria MP. Constructed wetlands as a sustainable solution for wastewater treatment in small villages. Biosys Eng. 2004; 87(1):109-118.
38. Tandukar M, Ohashi A, Harada H. Performance comparison of a pilot-scale UASB and DHS system and activated sludge process for the treatment of municipal wastewater. Water Res. 2007; 41(12):2697-2705.
39. Tayade ST, Ojha AR, Kumar R, Singh RN. Feasibility study of constructed wetland for treatment of municipal wastewater. Green Pages, Eco Services International, Switzerland, 2005, 2(22).
40. Ukiwe LN, Ibeneme SI, Duru CE, Okolue BN, Onyedika GO, Nweze CA, *et al*. Chemical and electrocoagulation techniques in coagulation-flocculation in water and wastewater treatment-a review. International J Research and Reviews in Applied Sci. 2014; 18(3):1.
41. USEPA. Guidelines for Water Reuse. USEPA, Cincinnati, OH: National Risk Management Research Laboratory. USAID (EPA/600/R-12/618), Washington, DC, 2012.
42. Von Sperling M, Freire VH, De Lemos Chernicharo CA. Performance evaluation of a UASB-activated sludge system treating municipal wastewater. Water Sci Technol. 2001; 43(11):323-328.
43. Vymazal J. Removal of organics in Czech constructed wetlands with horizontal sub-surface flow. Transformations of nutrients in natural and constructed wetlands. Backhuys, Leiden, 2001, 305-327.
44. Vymazal J. The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years' experience. Ecolog Eng. 2002; 18(5):633-646.
45. Vymazal J. Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. Ecolog Eng. 2005; 25(5):478-490.
46. Vymazal J. Constructed wetlands for treatment of industrial wastewaters: A review. Ecolog Eng. 2014; 73:724-751.
47. Watson JT, Reed SC, Kadlec RH, Knight RL, Whitehouse AE. Performance expectations and loading rates for constructed wetlands. Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Lewis Publishers, Chelsea Michigan. 7-tab, 73 ref, 1989, pp 319-351.
48. Zhang X, Wang Z, Wu Z, Lu F, Tong J, Zang L, *et al*. Formation of dynamic membrane in an anaerobic membrane bioreactor for municipal wastewater treatment. J Chem Eng. 2010; 165(1):175-183.