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Review

An overview of water pollution and constructed wetlands for sustainable wastewater treatment in Kathmandu Valley: A review

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Due to lack of strong legislation and guidelines to control untreated wastewaters and industrial effluents, surface and groundwater sources have been deteriorated seriously in Kathmandu Valley. Although, there are five centralized wastewater treatment plants in the valley, most of them are out of order. In recent years, constructed wetlands (CWs) have gained attention in the country for treating domestic wastewaters. The Nepal's first CW was introduced in 1997 to treat the wastewaters from Dhulikhel hospital. Since then the number of CWs have been increasing in Nepal. At present, there are 13 CW systems in operation for treatment of domestic wastewaters including grey water and fecal sludge. Relatively higher pollutant removal efficiency (>95%) in terms of suspended solids, organic pollutants and ammonium ion (NH_4^+-N) were found in all the existing CWs. Despite having higher removal rate of organic pollutants, CW technology is still in its infancy stage in Nepal. Therefore, further research and development is necessary for making the CW technology as a promising decentralized technology for treating wastewaters in Nepal.

Key words: Constructed wetland, domestic wastewater, scarcity of water, water pollution.

INTRODUCTION

The availability of freshwater resources on earth are diminishing rapidly due to less constant water supply and increasing world's population (Bruch et al., 2011; Kivaisi, 2001; Stikker, 1998). The increasing pace of urbanization especially in developing countries continues to affect the quality and quantity of freshwater detrimentally (Bruch et al., 2011; Karn and Harada, 2001). Already, many developing countries have been facing acute scarcity of water due to rapid and unplanned urbanization (Karn and Harada, 2001; Kivaisi, 2001; Stikker, 1998). In many developing countries, sewage wastewaters, industrial effluents and municipal wastewaters are discharged directly into the aquatic environments, and such indiscriminate discharge of polluted effluents further intensifies the shortage of water supply by deteriorating the quality of available freshwater (Dallas et al., 2004; Kivaisi, 2001; Shrestha et al., 2001a; Stikker, 1998).

Furthermore, water pollution especially surface waters in developing countries has become more severe and critical with rapid urbanization and lack of adequate sanitation (Kambole, 2003; Karn and Harada, 2001; Kivaisi, 2001). Throughout the world, 1.5 million children die annually from water-borne diseases especially diarrhea caused by lack of proper drinking water service (WHO, 2009). The scarcity of safe drinking water access is more critical in Africa and South Asia, where more than 80% of children deaths occur due to diarrhea each year (WHO, 2009). Thus, water pollution and freshwater depletion as a result of inappropriate discharge of polluted effluents from agricultural, industrial, and domestic/sewage activities are considered as the major

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environmental issues in Asian countries (ADB, 1997; Kambole, 2003). South Asian countries like Nepal, India and Bangladesh are suffering from acute scarcity of drinking water as well as water pollution mainly due to increasing unplanned urbanization and lack of formulation of plans and policy measures to control discharge of untreated wastewaters into the aquatic environments (Karn and Harada, 2001; Panthee, 2008; Shah Teli et al., 2008; Shrestha et al., 2001a).

AN OVERVIEW OF WATER POLLUTION AND SANITATION IN NEPAL

Nepal (28º 00'N; 84º 38'E) is a small landlocked country with a total area of 147,181 km^2 and varies between an altitude of 60 and 8,850 m. Nepal shares its political borders with China in the north and India in the east, west and south. The geographical structure of Nepal resembles a rectangle with three main ecological zones running horizontally as continuous belts, namely, mountainous, hills, and terai (Gautam et al., 2009). Nepal is bestowed with water resources where approximately 6,000 rivers and rivulets flow with a total drainage area of 194,471 km^2 (WECS, 2011). The average annual water runoff of the country is estimated at 225 billion m^3/s (Pokharel, 2001).

Despite the enormous water resources, there is persistent imbalance between the demand and supply for water in the country (Pant, 2011; Sharma et al., 2005; Warner et al., 2008). At present, approximately 58% of the populations are served with piped water supply in Nepal (DWSS, 2010). Similarly, 38% of the populations are served with handpump/boring water supply (DWSS, 2010). Whereas in the mountainous parts of the country, the majority of the populations depend on surface water (boring, spring, rainwater harvesting) for drinking, which is not safe from the health perspective (CBS, 2008; DWSS, 2010; Sharma et al., 2005). In addition, with the increasing population, demand for water is increasing rapidly for domestic requirements, agriculture and industrial sectors (MOI, 2010; Pant, 2011; Sharma et al., 2005). In terms of sanitation, Nepal lags behind all the South Asian countries, and only 43% of the population has accessed to improved sanitation (DWSS, 2010).

Due to varied geographical setting, the coverage of water and sanitation services is not uniformity in Nepal (WASH, 2011). The existing coverage of water and sanitation services varies between the urban and rural areas and also among the developmental regions (WASH, 2011; WHO/UNICEF, 2010). By the year 2010, only 37% of the rural population has sanitation services (NPC, 2010). Half of the rural population will have access to sanitation by 2015 (NMDG, 2010). Based on the geographical coverage, mountain has lowest water and sanitation services as compared to hill and terai regions (WASH, 2011). In addition, the Nepal Millennium Development Goals has targeted to expand safe drinking water of 95 and 72% in the urban and rural areas, respectively, by 2015 (NMDG, 2010; NPC, 2010).

Although, monitoring of water quality on regular basis is important, separation of domestic wastewaters and industrial effluents at the source is a largely undocumented practice in Nepal (Shah Teli et al., 2008; Sharma et al., 2005). The continued practice of discharging domestic and industrial wastewater directly into the aquatic environments (rivers, ponds, lakes, streams, etc.) is the primary causes of water pollution in Nepal (Shah Teli et al., 2008; Warner et al., 2008). In recent years, pollution of surface waters has become more severe and critical near the urban areas especially in Kathmandu, and thus, water pollution has become one of the most significant environmental problems in Nepal (Karn and Harada, 2001). Due to lack of sanitation and safe drinking water supply, Nepalese people are susceptible to severe health threats such as diarrhea, typhoid and dysentery (Warner et al., 2008; WHO, 2009). Diarrhea remained the major problem for Nepalese children and is recognized as the second most prevalent diagnosis in out-patient services (Diwakar et al., 2008; WHO, 2009).

WATER POLLUTION IN KATHMANDU VALLEY

Although, more than 80% of the Nepalese populations live in rural areas, the rate of urbanization is relatively high as compared to other South Asian countries (NPC, 2010; WaterAid, 2008). In recent years, the rate of urbanization became rampant and exerted more pressure on existing water resources as well as contaminated the drinking water resources in most of the municipalities and small towns in Nepal (WASH, 2011; WaterAid, 2008). As a result, surface and groundwater sources have been deteriorated seriously in Nepal (Karn and Harada, 2001; Pant, 2011; Panthee, 2008; Shah Teli et al., 2008). The problem of wastewater management is critical in Kathmandu, the capital city of Nepal (Karn and Harada, 2001; Pant, 2011; WaterAid, 2008). Kathmandu Valley is situated at an altitude of about 1,300 m above the sea level and has an area of approximately 650 km^2 (Gurung et al., 2007; Khatiwada et al., 2002).

Kathmandu Valley is densely populated (approximately 2.2 million people), which has five municipalities and constitutes the country's largest urban economy (Gurung et al., 2007; Khatiwada et al., 2002; Shrestha and Maharjan, 2009). In the urban and semi-urban areas of the Kathmandu Valley, most of the households rely on on-site sanitation facilities such as pit latrines, pour flush toilets and septic tanks (Shrestha et al., 2001a; Shrestha et al., 2001b; WaterAid, 2008). Haphazard disposal of untreated wastewater from households along with industrial and agricultural practices is exerting more pressure on water demand in the valley (Pandey et al.,

Table 1. Chemical characteristics of groundwater sample in Kathmandu Valley (Pant, 2011).

Groundwater source	Iron (mg/L)			Arsenic (mg/L)			Fluoride (mg/L)		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Shallow well (56)	0.1	5.5	1.47	0	0.025	0.004	0.06	1.92	0.43
Tube well (20)	0.1	4.9	1.9	0	0.01	0.003	0.07	0.53	0.27
Deep tube well (11)	0.12	5.2	1.8	0	0.025	0.009	0.13	1.76	0.74
WHO guidelines		0.3			0.01			1.5	

Table 2. Microbiological analysis of groundwater sample (Warner et al., 2008).

Groundwater source	*E. coli* (CFU/100 ml)				
	Minimum	Maximum	Mean	Median	Detected (%)
Dug well (37)	0	800	100	28.5	86
Shallow aquifer tube well (38)	0	81	10	1	55
Municipal sources (19)	0	750	70	12	76
Dhunge dhara (16)	0	500	107	44	73
Deep-aquifer tube well (5)	0	1	0.4	0	40

2010; Pant, 2011; Sharma et al., 2005). Since the valley does not have sufficient water supply facilities, more than 50% of the population relies on groundwater for drinking water and domestic uses (Khatiwada et al., 2002).

Overexploitation of water depleted the groundwater resources in the valley (Pandey et al., 2010; Pant, 2011). Apart from overexploitation, groundwater quality have been degraded due to anthropogenic activities such as disposal of unsafe solid and liquid household wastes, agricultural, and toxic industrial waste into the aquatic environments (Pant, 2011; Sharma et al., 2005). The intensive use of chemical fertilizers and pesticides further worsen the situation by contaminating the groundwater with heavy metals such as arsenic and mercury (Kannel et al., 2008; Pant, 2011; Sharma et al., 2005). The chemical analysis of groundwater sources in Kathmandu Valley is shown in Table 1.

The groundwater sources are not only polluted with chemicals but also contaminated biologically with *Escherichia coli* and Total coliform (Pant, 2011; Warner et al., 2008). Pant and others analyzed the groundwater sample including shallow well, tube well and deep tube well, and found that the total coliform extremely exceed the WHO guidelines (Pant, 2011). The main reason of this contamination may be due to poor drainage facility and lack of sanitation in the households (Pant, 2011). Table 2 shows the microbiological analysis of groundwater sample in the valley.

In addition to groundwater sources, water quality of the rivers and streams of Kathmandu Valley are severely deteriorated (Karn and Harada, 2001; Pandey et al., 2010). The continued disposal of untreated wastewaters into nearby rivers such as Bagmati and Bishnumati further degrade the environment in the valley (WASH, 2011; WaterAid, 2008). The characteristics of water quality in Bagmati river during the dry (May) and winter (December) seasons are shown in the Table 3.

WASTEWATER TREATMENT PLANTS IN KATHMANDU VALLEY

The acute shortage of water supply can be reduced by treating the domestic waters and industrial effluents in the wastewater treatment plants (Kivaisi, 2001). At present, there are five wastewater treatment plants in Kathmandu Valley, which are based on simple lagoon and oxidation ditch systems (Arata, 2003; Poh, 2003; WaterAid, 2008). Although, these treatment plants are technically very simple with no mechanized parts, they are not effective in treating wastewaters in the valley (Arata, 2003; Green et al., 2003; Poh, 2003). It was estimated that approximately 176 m^3/d of wastewater is generated from Kathmandu (with population approximately 2.2 million), however, the treatment efficiency of the existing treatment plants are just 37 m^3/d (Shrestha and Maharjan, 2009). Existing wastewater treatment plants in Kathmandu valley are shown in the Table 4. Additionally, most of the existing treatment plants are not operating at their full capacity (Arata, 2003; Green et al., 2003). Lack of financial capability is often associated with the failure of current wastewater treatment plants in Nepal (Green et al., 2003).

Moreover, poor operation and maintenance, and lack of expertise are some of the important reasons for the failure of centralized wastewater treatment plants in Kathmandu Valley (Poh, 2003; WASH, 2011; WaterAid, 2008).

In general, centralized wastewater treatment plants are

Table 3. Water quality of Bagmati River during dry and winter season (ENPHO, 2003).

Parameter	May, 2002	December,2002
pH	7	6.5
Turbidity (NTU)	100	180
TSS (mg/L)	166	144
BOD (mg/L)	240	109
COD (mg/L)	317	255
TDS (mg/L)	260	360
DO (mg/L)	0.7	1.9
NH_4^+-N (mg/L)	18	20
NO_3-N (mg/L)	0.6	>10
PO_4-P (mg/L)	1.7	1
Fecal coliform (per 100 mL)	230×10^4	1.8×10^4

Table 4. Existing wastewater treatment plants in Kathmandu Valley (ADB, 2000; Arata, 2003; Green et al., 2003).

Treatment plant	Capacity (m^3/d)	Type of plant	Year of establishment	Existing status
Sallaghari	2	Aerated lagoon	1983	Not operating
Hanumanghat	0.5	Aerated lagoon	1975	Not operating
Dhobighat	15.4	Stabilization pond	1982	Not operating
Kodku	1.1	Stabilization pond	1982	Operating inefficiently
Guheshwori	17.3	Oxidation ditch	1996	Operating

cost intensive and rely on sophisticated technologies and highly skilled personnel (Singh et al., 2009). Moreover, centralized wastewater treatment systems are also not environmentally friendly and consume more energy (Bruch et al., 2011; Kivaisi, 2001; Korkusuz et al., 2004; Singh et al., 2009). Though treatment plants are essential for reducing the gap between the water demand and supply, adequate attentions have not been paid by the government authorities on monitoring and management of existing centralized treatment plants in Kathmandu Valley (Green et al., 2003; Pandey et al., 2010). Therefore, it is necessary to adopt simple, efficient and cost-effective treatment technology for least developing countries like Nepal.

CONSTRUCTED WETLAND (CW) FOR TREATING DECENTRALIZED WASTEWATER

CWs have been used successfully worldwide for the treatment of municipal, industrial, landfill leachate, storm water and agricultural wastewater (Bruch et al., 2011; Kivaisi, 2001; Korkusuz et al., 2004). CWs for wastewater treatment can be applied in both cold and warm climates, and the technology is considered as suitable options for wastewater treatment and reuse in developing countries (Bruch et al., 2011; Dallas et al., 2004; Denny, 1997; Haberl, 1999; Kivaisi, 2001). CWs are simple in construction, process stability, low energy demand and cost effective (Korkusuz et al., 2004). In addition, this technology is environmentally sound option as it produces less sludge and potential for creating biodiversity as compared to centralized wastewater treatment plants (EPA, 1993; Korkusuz et al., 2004; Singh et al., 2009). CWs are generally designed to mimic natural wetland systems, utilizing wetland plants, soil and associated microorganism to remove contaminants from wastewater effluents, and also have high nutrient capturing capacity (CBS, 2008; Korkusuz et al., 2004; Singh et al., 2009).

There are various types of CWs which differ according to their design configurations (Cooper et al., 1996a; Haberl, 1999; UN-HABITAT, 2008). For example, based on the flow pattern, wetland can be classified as: free water surface flow, sub-surface flow, horizontal and vertical (Cooper et al., 1996b; Haberl, 1999). Similarly, based on the type of macrophytes used in the system, the wetland can be termed as free-floating, emergent and submerged (Cooper et al., 1996a; Haberl, 1999). In addition, the wetland system can be hybrid systems, one stage and multi-stage systems based on their configurations (UN-HABITAT, 2008). The most commonly used flow directions in the wetlands are horizontal flow (HF) and vertical flow (VF) (UN-HABITAT, 2008).

The most common type of CW system used for wastewater treatment is the sub-surface flow system,

Table 5. Pollutant removal mechanisms in CW (Cooper et al., 1996a).

Wastewater constituents	Removal mechanism
Suspended solids	Sedimentation, filtration
Soluble organics	Aerobic and anaerobic microbial degradation
Phosphorous	Matrix sorption, plant uptake
Nitrogen	Ammonification followed by nitrification, denitrification, plant uptake, matrix adsorption, ammonia volatilization
Metals	Adsorption and cation exchange, complexation, precipitation, plant uptake, microbial oxidation/reduction
Pathogens	Sedimentation, filtration, natural die-off, UBV irradiation, excretion of antibiotics from roots of macrophytes

which is also known as the reed bed treatment system (RBTS) (Dallas et al., 2004; Haberl, 1999; Kivaisi, 2001; Shrestha et al., 2001a; UN-HABITAT, 2008). The RBTS is simple in construction, which consist of a bed of uniformly graded sand or gravel with plants such as reeds growing on it (Cooper et al., 1996a; Shrestha et al., 2001b). Usually, *Phragmites karka* is used in this type of wetland and the media depth is typically range between 0.3 to 0.6 m (Cooper et al., 1996b; UN-HABITAT, 2008). Table 5 shows the removal mechanism of pollutant in the CW.

When wastewater is passed to the CW, it is distributed evenly on the bed and flows through it either horizontally or vertically based on the flow design (Cooper et al., 1996b; Haberl, 1999). As the wastewater flows through the bed of sand and reeds, it gets treated through natural processes like mechanical filtering, chemical transformations and biological consumption of pollutants in wastewater (Cooper et al., 1996a; Haberl, 1999; Shrestha et al., 2001a). In the case of VF, the wastewater flows vertically from top to the bottom of the bed, whereas in the case of HF, the wastewater flows from one end of the bed to another (Cooper et al., 1996a; UN-HABITAT, 2008). Usually, VF systems are more effective in removing organic contaminants compared to HF systems (Kivaisi, 2001; UN-HABITAT, 2008). Because in VF system, the beds are fed intermittently in a large batch flooding the entire surface and after a while the bed drains completely free, allowing air to refill the bed (Cooper et al., 1996a; Korkusuz et al., 2004). This kind of mechanism provides good oxygen transfer in the system (Korkusuz et al., 2004).

CW: AN ALTERNATIVE TO TREAT DOMESTIC WASTEWATER IN KATHMANDU VALLEY

Nepal has relatively a short history of using CWs for wastewater treatment and reuse. Due to failure of the centralized wastewater treatment plants, the Environment and Public Health Organization (ENPHO) initiated the introduction of a CW (small and decentralized treatment systems) technology in Nepal in 1995 (Green et al., 2003; Shrestha et al., 2001a; Shrestha et al., 2001b). In 1997, a pilot scale wastewater treatment plant based on CW was built in Dhulikhel hospital with the technical collaboration of the Institute for Water Provision, University of Agricultural Sciences, Vienna, Austria (Shrestha et al., 2001a; Shrestha et al., 2001b). A two staged sub-surface flow CW [HF followed by VF bed (VFB)] was designed and built (Shrestha et al., 2001a; Shrestha et al., 2001b). The features of the first Nepal's CWs are shown in the Table 6. The pilot plant was constructed for treating wastewater generated by the Dhulikhel hospital (Shrestha et al., 2001a). Initially the CW was built to treat 10 m^3/d of wastewater, however, it is successfully treating more than four times of that amount of wastewater (Shrestha and Shrestha, 2004; Shrestha et al., 2003; UN-HABITAT, 2008). CWs are effective in removing organic contaminants (>99%) if the system is properly designed and operated (Dallas et al., 2004). The Dhulikhel hospital treatment plant also showed high treatment efficiency throughout the investigation period (Shrestha et al., 2001a). When the system was fed with wastewater flow from 10 to 35 m^3/d, there was no difference in the removal efficiencies of biological oxygen demand (BOD_5), chemical oxygen demand (COD) and total suspended solids (TSS) (UN-HABITAT, 2008). In addition, the wastewater flow was increased up to 75 m^3/d and the effluent quality decreased as compared to wastewater flow of 35 m^3/d (UN-HABITAT, 2008). However, the effluent quality was still under the tolerance limits for the wastewater to be discharged into inland surface waters as set up by the Ministry of Population and Environment, Nepal (UN-HABITAT, 2008). The treatment efficiency of the Dhulikhel hospital CW treatment system is shown in Table 7.

The CWs technology has been replicated at several other places throughout the country after the successful

Table 6. Characteristics of Dhulikhel hospital constructed wetland treatment plant (Shrestha et al., 2001b).

Particular	Specification
Year of operation	1997
CW type	Sub surface flow
CW configuration	HF followed by VF
CW substrate	Sand, gravel
Type of wastewater	Hospital wastewater
Wastewater flow per day	10 m^3 in 1997/ 75 m^3 in 2006
Pre-treatment	Settlement tank-16.5 m^3
Type of feeding	Intermittent
Population equivalent (PE)	51 in 1997/ 386 in 2006
Total surface area of the CW	261 m^2(HFB-140 m^2 and VFB-121m^2)
Surface area per PE	5.1 m^2 in1997/0.7 m^2 in 2006
Surface area per m^3 volume of wastewater	26.1 m^2 in 1997/ 23.5 m^2 in 2006
Plant species	*Phragmites karka*

Table 7. The reed bed performance of the Dhulikhel hospital constructed wetland system (1997 to 2000) (Shrestha et al., 2001b).

Particular	Influent	Effluent	Removal efficiency (%)
TSS (mg/l)	82.92±58.19	2.283±1.946	97.25
NH_4^+-N (mg/l)	33.296±12.206	1.604±2.18	95.183
PO_4-P (mg/l)	7.908±7.483	4.223±5.757	46.6
BOD_5 (mg/l)	109.9±62.28	3.287±2.968	97.01
COD (mg/l)	324.5±272.8	20.2±14.2	93.8
E. coli (col/ml)	1E+08±2E+08	148±307	99.999

demonstration of the technology at the Dhulikhel hospital (Shrestha and Maharjan, 2009; Shrestha et al., 2001b). In order to improve the sanitation in the valley, a CW with the treatment capacity of 40 m^3/day was built for the Kathmandu Metropolis to treat the septage wastes (Shrestha et al., 2001a). The Kathmandu Metropolis treatment plant was operated in 1999 (Shrestha et al., 2001a). Similarly, a CW for the treatment of septage and landfill leachate was designed in Pokhara Sub-Metropolis (Shrestha et al., 2001a). The CW was designed to treat 100 m^3/day septage and 40 m^3/day landfill leachate in Pokhara (Shrestha et al., 2001b). Thereafter, the CW technology gained popularity for treating domestic wastewaters including grey water and sewage wastes (Shrestha and Maharjan, 2009; Shrestha et al., 2001a). In addition, CW has been constructed in few residential area for treating the grey water and septage (Shrestha and Shrestha, 2004; Shrestha et al., 2003). In general, all the CWs showed good performance in removing TSS, BOD, COD, and ammonium ion (NH_4^+-N) (Shrestha et al., 2001a; Shrestha et al., 2001b; Shrestha et al., 2003; WaterAid, 2008). As shown in Table 8, there are 13 CWs in Nepal.

FIRST COMMUNITY-BASED WASTEWATER MANAGEMENT THROUGH CW

The first community-based municipal wastewater treatment plant through CW was constructed in Madhyapur Thimi, Sunga Tole, one of the old Newar community in the Kathmandu Valley (WaterAid, 2008). The CW consists of a coarse screen and a grit chamber for preliminary treatment, an anaerobic baffle reactor (42 m^3) as primary treatment, HF followed by VFB for secondary treatment and two sludge drying beds for treating sludge (UN-HABITAT, 2008; WaterAid, 2008). The technical description of Sunga community-based CW is shown in Table 9.

The Sunga CW is treating municipal wastewater from 80 households though the treatment plant has a capacity to treat wastewater from 200 households (WaterAid, 2008). The Sunga CW plant receives an average daily flow of an 10 m^3 of very high strength wastewater (average BOD_5 of raw wastewater is 1,775 mg/L) (Singh et al., 2007; WaterAid, 2008). The overall performance of the wetland in removing pollutants remained quite efficient for the first year of operation (Singh et al., 2007).

Table 8. List of CWs in Nepal (Shrestha and Shrestha, 2004; UN-HABITAT, 2008).

Location	Date of operation	Q (m^3/d)	CW type	Size of the CW
Dhulikhel hospital	1997	40	HFB followed by VFB	S.T-10 m^3, HFB-140m^2, VFB-121m^2
Private house, Kathmandu	1998	0.5	VFB	S.T-0.5 m^3, VFB-6 m^2
Kathmandu Metropolitan city	1998	40	SDB followed by VFB	S.T-40 m^3, SDB-225 m^2, VFB-362 m^2
Malpi International school	2000	25	HFB followed by VFB	S.T-25 m^3, HFB-136 m^2, VFB-231 m^2
SKM P.R.S Hospital	2000	15	HFB followed by VFB	S.T-10 m^3, HFB-72 m^2, VFB-69 m^2
Kathmandu University	2001	40	HFB followed by VFB	S.T-40 m^3, HFB-290 m^2, VFB-338 m^2
Staff Quarter of MMHEPS	2002	26	HFB followed by VFB	S.T-13 m^3, HFB-148 m^2, VFB-150 m^2
ENPHO Lab	2002	1.5	VFB	S.T-500 L, HFB-18 m^2
Kapan Monastery	2003	17	HFB followed by VFB	S.T-7 m^3, HFB-50 m^2, VFB-150 m^2
Pokhara sub-Municipality city	Under operation	115	SDB followed by HFB and VFB	HFB-1180 m^2, VFB-1500 m^2 and SDB each of 235 m^2
Private house, Kathmandu	2002	0.5	VFB	S.T-0.5 m^3, VFB-6 m^2
Shuvatara school	2004		VFB	S.T-4 m^3, VFB-95 m^2
Sunga, Thimi	2005	25	HFB followed by VFB	S.T-42 m^3, HFB-150 m^2, VFB-150 m^2, SDB-70 m^2

ST, Settlement tank; SDB, sludge drying bed; MMHEPS, middle Marsyangdi hydro-electric power station.

The removal efficiencies of the wetland in 2006 for TSS, BOD_5 and COD were 98, 97 and 96%, respectively (Singh et al., 2007). Table 10 shows the overall performance of the Sunga CW in 2006.

PROSPECTS OF CWS FOR SUSTAINABLE WASTEWATER TREATMENT IN NEPAL

As already mentioned that cost effectiveness, environmentally friendly, simple in construction and process stability are some of the important features of CWs (Haberl, 1999; Singh et al., 2009; UN-HABITAT, 2008). Nepal is one of the least developed countries in the world with low per capita income (average of USD 470) (CBS, 2008). Nepal has a low human development index (HDI of 0.509) as compared to other South Asian countries, and it is estimated that approximately 25% of the populations live below poverty line (an income of less than USD 1.25/day) (UNDP, 2009). Therefore, from the financial perspective decentralized CWs will be viable option for treating wastewaters as compared to centralized wastewater treatment systems in Nepal (Shrestha and Maharjan, 2009; Shrestha et al., 2003; Singh et al., 2009). The total cost for the construction of the CW depends on the type of materials used for the bed (Dallas et al., 2004; Kivaisi, 2001; Shrestha et al., 2001a). Table 11 shows the total cost invested for the construction of CWs in Nepal.

Peri-urban areas in developing countries are characterized by a mixture of land uses associated with a range of urban and rural livelihoods, and also people with different economic status can be found on those areas (Parkinson and Tayler, 2003). Same situation is happening in Nepal, and already the capital city is experiencing a high population growth rate of about 3.3 annually (Khadka and Khanal, 2008; Prasai et al., 2007). The average water demand in the Kathmandu Valley is about 180 m^3/d in which only 140 m^3/d of water is being supplied in the rainy season (Khadka and Khanal, 2008). The situation become even more severe in the dry season and only half of the total demand of drinking water is being supplied in winter (Khadka and Khanal, 2008; Prasai et al., 2007).

The growing imbalance between water supply and demand can only be maintained if the wastewaters are being treated and reused for agricultural and other purposes (Bruch et al., 2011; Kivaisi, 2001). It is estimated that approximately 370 m^3/d of wastewaters produce in Nepal in which 176 m^3/d is generated from the Kathmandu Valley alone (Shrestha and Maharjan, 2009; WaterAid, 2008). However, the installed capacity of wastewater treatment plants is only 37 m^3/d (WaterAid, 2008). Moreover, the existing plants are not in operation in regular basis and only 17.5 m^3/d of wastewaters is treated in the centralized wastewater treatment plants (Green et al., 2003; Nyacchyon, 2006; WaterAid, 2008). In recent

Table 9. Technical description of Sunga CW in Thimi (UN-HABITAT, 2008).

Particular	Specification
Date of operation	2005
CW type	Sub surface flow
CW configuration	HF followed by VF
CW substrate	Sand, gravel
Type of wastewater	Municipal wastewater
Wastewater flow per day	10 m^3
Pre-treatment	Anaerobic baffle reactor- 42 m^3
Type of feeding	Continuous in HFB, intermittent in VFB
Population equivalent (PE)	285.7
Total surface area of the CW	300 m^2 (HFB-150 m^2 and VFB-150 m^2)
Surface area per PE	1.05
Plant species	*Phragmites karka*

Table 10. Concentrations of pollutants at Sunga CW in 2006 (UN-HABITAT, 2008).

Parameter	Raw	ABR	HFCW	VFCW
TSS (mg/L)	796	204	28	16
BOD_5 (mg/L)	950	450	165	30
COD (mg/L)	1438	1188	213	50
NH_4^+-N (mg/L)	145.5	408.9	214.1	21
NO_3-N (mg/L)	4.1	36.8	32.6	566.2
PO_3-P (mg/L)	26.4	44.3	20.4	24.3
Fecal coliform (CFU/1 ml)	1.3E+5	1.3E+6	1.1E+6	8.1E+3

ABR, Anaerobic baffle reactor.

Table 11. Summary of cost considerations for CW in Nepal (UN-HABITAT, 2008).

CW plant	Total construction cost (US$)	Per m^2 (US$)	Operation and maintenance cost/year (US$)
Dhulikhel hospital	16,000	60	150
ENPHO lab	570	40	
Kathmandu University	26,000	40	290
Sunga, Thimi	31,500	85	520
Private house, Kathmandu	520	85	
Pokhara sub-Municipality	85,700	20	

years, CWs have shown some promise to treat and reuse the wastewaters (Shrestha et al., 2001a; Shrestha et al., 2003). Being simple in construction and operation as well as cost-effective, the CWs technology has potential to treat various types of wastewaters ranging from grey water to septage and landfill leachate (Bruch et al., 2011; Korkusuz et al., 2004; Singh et al., 2009; WaterAid, 2008). The technology is already proved to be effective in removing organic pollutants and inorganic contaminants in Nepal (Shrestha et al., 2001a; Shrestha et al., 2001b; Shrestha and Shrestha, 2004; Shrestha et al., 2003).

Nevertheless, the CWs technology has long way to go to be adopted at large scale real time application to treat wastewaters in Nepal (Shrestha et al., 2001a). There are some barriers for the promotion and implementation of the CW technology in Nepal (WaterAid, 2008). Despite having higher efficiency in removing organic and inorganic contaminants, the CW technology is relatively new to Nepal, and thus, it is unknown to majority of the populations (WaterAid, 2008). Being new technology in the country, some of the existing wetlands were poorly designed and constructed (Shrestha et al., 2001a). Lack of maintenance and regular monitoring are another problems associated with the use of CWs in Nepal (Shrestha et al., 2001a; WaterAid, 2008). Although the CW is cheaper than centralized wastewater treatment systems, the technology still can be expensive for populations having low-income (Dallas et al., 2004). In addition, large area is required for construction of wetland which might not be possible in densely populated cities like Kathmandu (UN-HABITAT, 2008). Moreover, neither wastewater treatment is a priority for the government authorities, private industrialists and institutions nor government enforces the strong legislation and guidelines for the polluters (WaterAid, 2008).

CONCLUSION

The CW technology to treat wastewaters is relatively a new technology in Nepal. In recent years, the CW has shown potential to treat and reuse wastewaters in Nepal. This technology is cost-effective and environmentally better options as compared to centralized wastewater treatment systems. However, the technology has still a long way to be adopted all over the country. At present, lack of knowledge and experience has resulted in poor design and management of the CWs in Nepal. Nonetheless, this technology can be viable option for reducing the water supply gap among the unplanned and urbanized city like Kathmandu, which is already suffering acute scarcity of water supply. Thus, continuous research and development are needed to test the viability of this technology for the effectiveness of wastewater treatment.

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