Status of Constructed Wetlands in Nepal: Recent Developments and Future Concerns

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네팔에서의 인공습지 적용: 최근 개발 및 향후 고려사항

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Abstract

Nepal is a landlocked mountainous country in South Asia, located between China to the north and India to the south, east, and west. As such, wastewater management has become one of the most significant problems in urban area of Nepal. In Nepal, the centralized wastewater treatment systems were dysfunctional due to high cost of operation, discontinuous power supply, lack of proper maintenance and proper technical workforce to address the issues. As such, constructed wetlands (CW) were applied to treat various secondary wastewater as alternative to wastewater treatment facilities. Generally, efficiency and sustainability of CW technology depends on proper operation and maintenance and active community involvement. This study summarizes information about 26 CW in Nepal. Specifically, factors including data banking, removal efficiency, quality of discharged water, compliance to water quality standard of Nepal and operation and maintenance were investigated. Considering removal efficiency per pollutant, Ka-1 achieved the greatest reduction for most pollutant followed by B-1, L-3, Ka-5 and K-1. Nepal has practiced CW technology for more than 2 decades but currently, development of technology was interrupted by the inefficient performance of existing facilities. Public awareness about the technology, natural disaster, unavailability of specified substrate materials, lack of fund for further research and experiments has hindered the expansion of technology. In spite of these concerns, CW was still proven as an alternative solution to the present wastewater problems in urban areas of Nepal.

Key words : Constructed Wetland, Development, Nepal, Secondary Wastewater treatment

요 약

네팔은 중국과 인도 사이에 위치한 남부 아시아의 내륙국가로 폐수관리는 도시지역에서 가장 중요한 문제 중 하나이다. 네팔의 폐수처리 시스템은 비싼 운영비, 불연속적인 전력 공급, 유지관리 및 기술인력의 부족으로 인해 조성과 운영이 어렵다. 이러한 이유로 인공습지는 폐수처리시설의 대안기술로써 다양한 지역에 적용되고 있다. 일반적으로 인공습지 기술의 효율 지속 가능성은 적절한 운영과 유지관리 및 적극적인 지역사회 참여에 의존한다. 따라서 본 연구에서는 26개의 인공습지에서의 제거 효율, 방류수질, 네팔 수질기준, 운영 및 유지관리 활동 등을 조사하고 문제점을 분석하여 관리방안 등을 도출하였다. 오염물질당 제거효율은 ka-1의 인공습지가 가장 높은 것으로 나타났으며, B-1, L-3, Ka-5, k-1 순으로 높은 것으로 나타났다. 네팔의 인공습지 조성기술은 최근 20년간 기술개발 없이 전통적 방식에 의존해온 결과 비효율적인 성능으로 인해 많은 습지가 가동이 중단되거나 폐쇄되는 것으로 나타났다. 또한 기술개발의 부족, 자연재해, 대중의 인공습지에 대한 낮은 인식 및 예산 부족 등은 인공습지의 지속적인 개발을 저해하고 있는 것으로 조사되었지만, 인공습지는 네팔 도시지역의 폐수문제에 대한 해결방안으로 고려되고 있다.

핵심용어 : 인공습지, 개발, 네팔, 폐수처리

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1. Introduction

Nepal is a landlocked mountainous country in South Asia, bounded by China to the north and India to the south, east, and west, with coordinates at latitudes 26° 22'N to 30° 27'N and longitudes 80° 04'E to 88° 12'E. Nepal has diverse topography, geology and climate creating opportunity and constraints for various land uses and livelihood with total land area of 147,181 km². For these reasons, wastewater management has been one of the most significant problems in urban areas of Nepal. Wastewater produced from residential and commercial complexes and industries discharged to sources of water for dilution has turned rivers into an open sewer (Shrestha, 1999). The development of sewer systems started after the construction of 55 km long sewer line in Kathmandu and Patan in 1920 (Regmi, 2013). The development of water supply and sanitation infrastructure in the country began after 1972 under the support of the World Bank, focused on the improvement of Kathmandu Valley (Shukla et al., 2014). The survey conducted within Kathmandu valley by Binnie & Partners from United States of America, in 1970 recommended stabilization pond to treat 17 million liters per day (MLD) wastewater (IGES, 2016). After four to five years of operation, the system was hindered (Shrestha, 1999).The latest statistics of urban growth revealed that wastewater produced in ten major cities from 1981 to 2011 was estimated to be 147.37 MLD (Shukla et al., 2014). The volume of wastewater produced in the urban areas increased significantly which was attributed to increase in population, unplanned growth and rapidly changing water consumption patterns (IGES, 2016).

According to Ramsar convention, wetlands are categorized in three types namely inland, coastal or marine and human made which supports biodiversity as biological system (Sespene, 2016). Constructed wetlands (CW) are human made engineered systems used to treat wastewater replicating natural processes involving vegetation, soils, and associated microbial assemblages (UN-Habitat, 2008). Based on hydrology, CW was classified as free water surface and subsurface systems which were further classified based on flow direction (horizontal and vertical). In the early days, CW technology was only applied to treat secondary municipal and domestic wastewater treatment facility effluent. At present, CW technology is also used for secondary treatment of wastewater from livestock, industrial, and agricultural wastewater, storm water and mine water (Kadlec and Wallace, 2009). This study summarizes information about CW in Nepal and compared

it to application in other countries. Specifically, the development, current status and future concerns about CW in Nepal were investigated.

2. Material and Methods

2.1 Driving forces for constructed wetland in Nepal

In Nepal, the urban areas are expanding without demographic, municipal, regional planning including infrastructure for wastewater management (Shrestha, 1999). The centralized wastewater treatment systems constructed within Kathmandu valley were dysfunctional due to high cost of operation, discontinuous power supply, lack of proper maintenance and proper technical workforce to address the problem (Green et al., 2003). The typical wastewater treatment plant is using bar screens and grit chambers as preliminary treatments followed by Anaerobic Baffle Reactor (ABR) or septic tanks working as primary treatment facilities demonstrated in Fig 1. Polishing ponds are used as post treatment facilities. A pilot scale CW technology was introduced in 1997 by Environment and Public Health Organization (ENPHO), Nepal in collaboration with the Institute for Water Provision, University of Agricultural Sciences, and Vienna, Austria. Local government units, UN-Habitat, ENPHO and users' community groups supported the use of CW technology (Shrestha, 1999). Presently, a total of 26 CW were built as secondary treatment of wastewater from different sources.
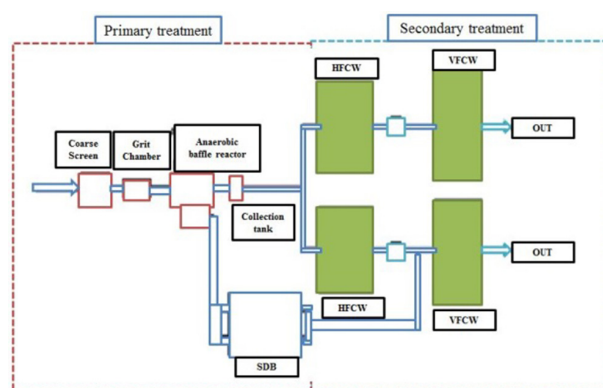

Fig. 1. Schematic of typical wastewater treatment system in Nepal (Adapted from Singh et al., 2009)

2.2 Synopsis of Constructed wetlands in Nepal

Table 1 summarizes the information about CW in Nepal. CW received secondary wastewater from residential and industrial areas. Referring to Fig 1, 22 CW are within Kathmandu valley and adjacent districts. Eastern and western development region has one and three CW,

respectively. Mid-western and far western development regions have no CW facility. The total area covered by CW technology in Nepal is 6734.1 m^2 treating an average flow of 512.5 m^3/day. 67% of the daily average flow was diverted to CW by the central development region while 33% was the combined flow of the other development regions. Similarly, 56% of the total land area covered by CW technology in Nepal was in central development region while the remaining 44% was from other development regions. Typically, crushed gravel and sand were used as substrate materials to grow plants like *Phragmites karaka* and *Canna latifolia.*

Fig. 2. Locations of constructed wetlands in Nepal

Table 1. Constructed wetlands in Nepal

Location of CW	District	Source of wastewater	Date constructed	Average flowrate m^3/day	HFCW[2] surface area m^2	[3]VFCW surface area m^2	References
Dhulikhel Hospital (K-1)	Kavre	Hospital	1997	40	140	112	ENPHO
Dallu, Private House (Ka-1)	Kathmandu	Residence	1998	0.5	–	6	ENPHO
Teku wastewater treatment plant (Ka-2)	Kathmandu	Community	1998	40	–	362	UN-Habitat
Malpi International School (Ka-3)	Kathmandu	School	2000	25	136	231	Murthy et al., 2007
SKMPRSH (Ka-4)[1]	Kathmandu	Hospital	2000	15	72	69	ENPHO
Kathmandu University (K-2)	Kavre	University	2001	40	290	338	UN-Habitat
MMHEPS Staff quarter (Lam-1)	Lamjung	Institutional	2002	26	148	150	Shrestha and Maharjan, 2009
ENPHO Laboratory (Ka-5)	Kathmandu	Community	2002	1.5	–	15.5	ENPHO
Kapan Monastery (Ka-6)	Kathmandu	Institutional	2003	17	50	150	Gurung and Oh, 2012
Private House (Ka-7)	Kathmandu	Residence	2002	0.5	–	6	ENPHO
Pokhara Sub-Metropolitan City (Kas-1)	Kaski	Community	2003	115	1180	1500	Gurung and Oh, 2012
Shuvatara School, Lamatar (Ka-8)	Kathmandu	School	2004	–	–	95	Gurung and Oh, 2012
Surya Tobacco Co. Pvt. Ltd. (M-1)	Makawanpur	Industrial	2005	NA	–	–	Shrestha and Maharjan, 2009
Private House, Bishal Nagar (Ka-9)	Kathmandu	Residence	2005	NA	–	–	ENPHO
Sunga, Thimi (B-1)	Bhakatapur	community	2005	25	152	160	ENPHO
Kirtipur Housing Community (Ka-10)	Kathmandu	Community	2006	NA	–	–	Shrestha and Maharjan, 2009
Kusunti Housing (L-1)	Lalitpur	Community	2007	NA	–	–	Shrestha and Maharjan, 2009
Ilam Polyclinic (I-1)	Illam	Hospital	2007	NA	–	–	Shrestha and Maharjan, 2009
Sano Khokana Community (L-2)	Lalitpur	Community	2008	15	225	–	ENPHO
Srikhandapur (K-3)	Kavre	Community	2008	103	1050	–	ENPHO
Pharping,Monastary (Ka-11)	Kathmandu	Institutional	2009	NA	–	–	Shrestha & Maharjan, 2009
Private House at Kirtipur (Ka-12)	Kathmandu	Residence	2010	5	–	2.6	ENPHO
Tansen Municipality (P-1)	Palpa	Municipality	NA	30	–	`–	Shrestha and Maharjan, 2009
ICIMOD, Lalitpur, L-3	Lalitpur	Institutional	2010	6	–	39	ENPHO
AMAGHAR Godavari (L-4)	Lalitpur	Domestic	2011	8	55	–	ENPHO
Nala (K-4)	Kavre	Community	2012	–	–	–	Davies et al., 2015

[1]SKMPRSH = Sushma Koirala Memorial Plastic & Reconstructive Surgery Hospital, [2]HFCW= Horizontal Subsurface flow constructed wetland, [3]VFCW = Vertical subsurface flow constructed wetland

2.3 Types of CW used in Nepal

Typical types of CWs used in Nepal were horizontal and vertical subsurface CW which were combined (referred as hybrid) to maximize the performance of both systems. The HFCW were well suited for removal of BOD, TSS for secondary effluent whereas VFCW required less land area and better oxygen transfer for nitrification (UN–Habitat, 2008). Hybrid CW was used as secondary treatment facilities for wastewater. The effluent from primary treatment was delivered continuously to HFCW and intermittently to VFCW including percolate effluent from sludge drying bed for treatment.

3. Results and Discussion

3.1 Status Assessment of Constructed wetlands in Nepal

Bagmati River Sundarighat in Kathmandu was used as reference to compare the discharged water quality of all CW in river quality shown in Table 2. It was found that 65% of the CW practiced good monitoring and data banking which can be used as future reference to improve CW performance. On the other hand, only 7 CW which were all located in the central development region demonstrated positive pollutant removal. The water quality discharged by eight CW was better than Bagmati River Sundarighat, implying that this CW contributed to improve the river water quality. Among 26 CW, only 3 were compliant to the agricultural water quality standards of Nepal considering total suspended solids (TSS), biological oxygen demand (BOD) and total phosphorus (TP) effluent concentrations. Based on five factors, K–1, Ka–1, Ka–5, B–1 and L–3 were selected as representative CW in each area of Nepal.

Apparent in Fig 3, the maximum average influent TSS, BOD and chemical oxygen demand (COD) concentration was observed in B–1. The effluent TSS, BOD and COD

Table 2. Status Assessment of constructed wetlands in Nepal

Location of CW	Factors								
	Good monitoring and data banking	Positive pollutant removal efficiency	Better discharged water quality compared to Bagmati River Sundarighat, Kathmandu			Compliance to water quality standards (for agricultural purpose)			Operational & maintained
			TSS	Organics	Nutrients	TSS	BOD	TP	
K–1	✔		✔	✔	✔	✔	✔	✔	✔
Ka–1	✔	✔	✔	✔	✔	✔	✔	✔	✔
Ka–2	✔								ND
Ka–3	✔								ND
Ka–4	✔	✔	✔	✔		✔			✔
K–2	✔								✔
Lam–1	✔								ND
Ka–5	✔	✔	✔	✔	✔	✔	✔	✔	✔
Ka–6	✔								ND
Ka–7	✔	✔				✔		✔	ND
Kas–1	✔								ND
Ka–8	✔								ND
M–1									ND
Ka–9									ND
B–1	✔	✔	✔	✔	✔				ND
Ka–10									ND
L–1									ND
I–1									ND
L–2	✔			✔			✔		✔
K–3	✔	✔	✔	✔	✔				ND
Ka–11									ND
Ka–12	✔								ND
P–1									ND
L–3	✔	✔	✔	✔			✔		ND
L–4			✔	✔		✔			✔
K–4									ND

by B-1 CW were 14%, 72% and 26%, respectively higher than the national water quality standards of Nepal. These findings were attributed to higher inflow rate in B-1 compared to other CW. Fig 4 represents the pollutant removal efficiency of representative CW in Nepal. TP removal was observed to be significantly lower than the other pollutants with negative removal by K-1 and Ka-1. This finding was mainly due to the use of substrate material with low concentration of Ca, Al and Fe metals for sorption including low phosphorus uptake capacity of plants used in CW (Murthy et al., 2007). Based on the ranking of removal efficiency per pollutant, Ka-1 achieved the greatest pollutant reduction followed by B-1, L-3, Ka-5 and K-1. As shown in Fig 5, the cost per area of CW decreases as the inflow rate increases. This finding was useful for designing and estimating construction cost of similar CW in Nepal for future use. K-1 had the cheapest construction cost amounting to 22.7 $/m^2 with an average flowrate of 40 m^3/day. On the other hand, L-3 had the most expensive construction cost of 172.8 $/m^2 with an average flowrate of 6 m^3/day.
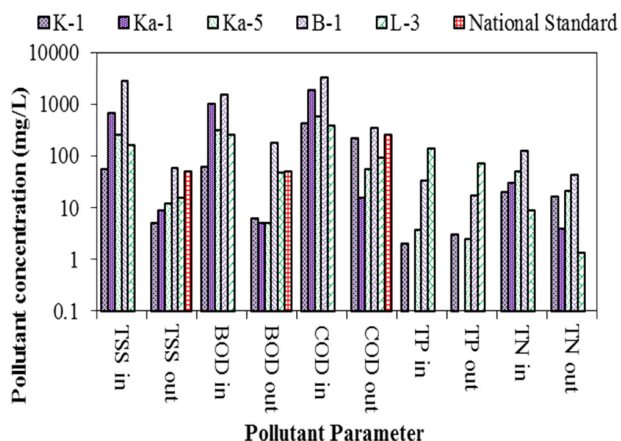

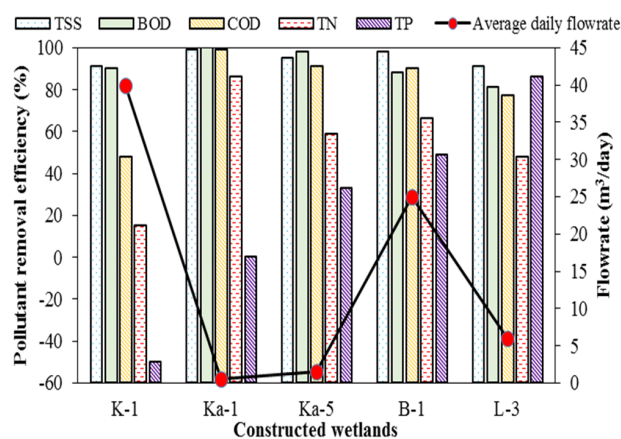Fig. 3. Pollutant concentration changes in each representative CW

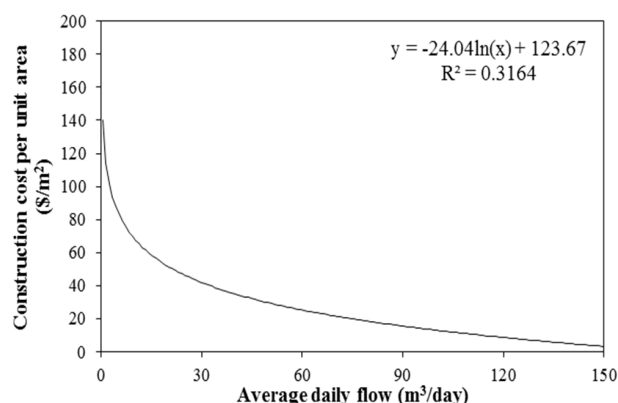Fig. 4. Pollutant removal efficiency of representative CW

Fig. 5. Logarithmic regression model of inflow rate to construction cost

3.2 Operation and Maintenance

Sustainability of any technology depends on proper operation, timely maintenance, and active community participation. Nepal practices formation of users' community group from beneficiaries' households for the overall management and maintenance of CW in communities (UN-Habitat, 2008). Users' community group was responsible in assigning a caretaker for daily operation, quarterly removal of unwanted plants and biannual common reed harvesting (Shrestha, 1999). On the other hand, operation and maintenance of institutional constructed wetlands were usually guided by provisions developed by the management. The operation & maintenance and resource mobilization of Sunga CW was conducted by Sunga wastewater treatment plant management Committee and trained caretaker was assigned with daily activities like unclogging screen and plant harvesting (ENPHO, 2010). The involvement of community in operation and maintenance and resource mobilization has led the sustainability of CW technology (Shrestha and Maharjan, 2009).

3.3 Status and Future Concern of Constructed wetland in Nepal

Public awareness regarding CW technology was the major challenge for the CW technology development (Shrestha and Maharjan, 2009). It was often difficult to involve community, institutions, and organizations for the installation of technology. The consideration of system as a low maintenance technology led to carelessness during operation and maintenance (Shrestha, 1999). Even though the cost of technology was low due to use of local materials for installation, high cost required for land acquisition and lack of proper specified standard substrate material made the technology expansion difficult (Gurung and Oh, 2012). Further, wastewater treatment was not the priority for

government, private industries, and institutions due to the lack of strong legislation and standards (Pudasaini, 2008). Urban and rural areas of Nepal can use CW technology to solve wastewater treatment problem. The effluent produced from the CW can be used as irrigation water to increase agricultural activity. CW was proven as an alternative solution to the present wastewater problems in urban areas of Nepal since the construction of long sewer line was economically impossible for centralized wastewater treatment in most part of Nepal due to diverse topography (Shrestha and Maharjan, 2009). The sub-tropical climatic condition of urban areas of Nepal stimulated better growth of rhizosphere plant which led to better biological activity in soil for CW performance (Murthy et al., 2007).

3.4 Comparison of Constructed Wetlands

Overall, the effluent of CW in China was found to have lowest concentration followed by the Nepal, Netherlands, USA and South Korea apparent in Table 3. CW in Netherlands were used to treat recreational wastewater which produced relatively high TSS and COD concentrations compared to domestic, industrial and agricultural wastewaters treated by CW in other countries. CW in China uses different types of substrate materials compared to other countries resulting to lower discharged COD, TN and TP concentrations. Greater TSS, BOD and COD removal efficiencies were exhibited by the CW in Netherlands

amounting to 99%, 95% and 80%, respectively. On the other hand, greatest TN and TP removal were attained by CW from USA and China, respectively. Least TSS and BOD removal was exhibited by CW from USA were attributed to the gravel substrate employed. Lastly, lowest COD, TN and TP removal was observed in CW of Nepal due to the vegetation used which was the locally available species of Phragmites genus.

4. Conclusion

CW technology has been widely used due to its ease of operation, cost-effectiveness and low operation and maintenance cost (Mercado, 2013). In Nepal, CW was used to treat secondary domestic, municipal and industrial wastewater to prevent the surface waters bodies from turning into an open sewer. 85% of the CW was located in central development region where Kathmandu valley is located. It was found that based on factors including data banking, removal efficiency, quality of discharged water, compliance to water quality standard of Nepal and operation and maintenance, K-1, Ka-1, Ka-5, B-1 and L-3 were selected as representative CW. Considering removal efficiency per pollutant, Ka-1 achieved the greatest reduction for most pollutant followed by B-1, L-3, Ka-5 and K-1. One of the best practices of Nepal in terms of operation and maintenance was the involvement of community which led to the sustainability of CW technology in Nepal. Although

Table 3. Comparison of constructed wetlands

Parameter	Nepal		South Korea		China		USA		Netherlands	
Reference	ENPHO, 2010		Yoon et al., 2001		Liu et al,2008		Steer et al., 2001		Voerhoven et al., 1998	
Sources of secondary wastewater	Institutional		Domestic		Domestic, industrial and agricultural		Domestic		Recreational	
Types of CW	HFCW and VFCW		HFCW		FWS, HFCW, VFCW and hybrid wetlands		HFCW		Infiltration wetland	
Substrate	Coarse sand & gravel		Sands		Zeolite, gravel, soil, limestone, coal ash, slag, grit		River bed gravel		Coarse sand	
Vegetation	*Phragmites karkaa*		Reeds		*Phragmites australis, Typha latifolia and Canna indica*		*Bulrushes or arrowhead, Acorus calamus, Lobelia carinalis and Asclepias incarnata*		*Phragmites australis*	
Concentration	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
TSS (mg/l)	55	5	ND	13	ND	ND	62.1	17.3	700	7
BOD (mg/l)	60	6	345	24	113	20.6	77	18.4	180	9
COD (mg/l)	432	223	ND	ND	234.7	62.5	ND	ND	500	100
TN (mg/l)	19.5	16.5	100.74	81	24.1	13.4	32.3	16.7	43.08	28
TP (mg/l)	2	3	13.6	8	2.9	1.1	3.75	2.41	10	7.5

ND signifies unavailable data

the CW of Nepal was observed to have higher discharged TSS, BOD and COD concentration, the nutrient concentration discharged by this CW were almost in the same range with CW from other countries. The consideration of system as a low maintenance technology led to carelessness during operation and maintenance and lack of strong legislation and standards remained as the main challenges encountered by advocates of CW in Nepal. In spite of these challenges, CW was still proven as an alternative solution to the present wastewater problems in urban areas of Nepal. This was because the construction of long sewer line for centralized wastewater treatment was economically impossible in most part of Nepal due to diverse topography.

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