7 Decentralised wastewater management using constructed wetlands

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Abstract

Environment management is a significant challenge in developing countries mainly due to lack of strong legislation to control wastewater and institutional capacity for integrated planning and management. This paper describes the importance of small scale decentralized wastewater treatment using reed bed treatment systems (RBTS) in Nepal. It shows how public/community participation can support small scale construction work while ensuring checks on quality and price of construction. It includes examples where this system provides good quality, low-cost services.

Environmental Public Health Organisation (ENPHO) introduced the system in Nepal through research and then by designing and constructing a pilot-scale wastewater treatment system in Dulikhel Hospital in 1997. Since then this has been followed by 13 such systems at various institutions (e.g. hospitals, schools, university, and monastery) and individual households. The system is found to be highly effective in removing pollutants such as suspended particles, ammonia-nitrogen, BOD, COD and pathogens.

With the experience of designing the system and more than eight years of monitoring and evaluation of the system, the challenge was to upscale this technology to a community scale. To overcome this challenge a community scale wastewater treatment system was designed for Madhaypur Thimi Municipality, a first of its kind in Nepal. As the local people in Madhaypur Thimi Municipality showed interest in wastewater treatment, ENPHO with support of

the Asian Development Bank (ADB), UN-Habitat and WaterAid Nepal (WAN) constructed a wastewater treatment system in Sunga area. The treatment plant has the capacity to treat 50m^3 of wastewater per day. The local community has formed a committee for construction and future O&M of the RBTS. This RBTS will set a valuable precedent for other larger systems in other parts of the country as well as systems envisaged under national urban development projects in Nepal, such as the Urban Environment Improvement Project.

Introduction

Haphazard disposal of untreated wastewater from households as well as institutions and industry is causing severe deterioration of water bodies in many urban areas in the developing world. Most cities do not have adequate systems for the collection and treatment of wastewater and this is usually not considered to be a priority for investment. It is estimated that in developing countries, 300 million urban residents, 34% of them in South Asia, have no access to sanitation (WaterAid Nepal, 2006). Approximately two-thirds of the population in the developing world has no hygienic means of disposing of excreta and an even greater number lack adequate means of disposing of wastewater. This is a major public health risk as it can lead to outbreaks of diseases such as diarrhoea, cholera, and typhoid.

Although urbanisation is a relatively new phenomenon in Nepal, with only about 15% of the population living in urban areas, the rate of urbanisation is very high. This rapid urbanisation is haphazard and so exerts immense pressure on the urban environment. Municipal managers often lack the expertise and resources to deal with this issue. As a result, urban sanitation has become a major challenge for municipalities and small towns in Nepal. Most of the urban and semi-urban areas of the country rely on on-site sanitation facilities such as pit latrines, pour flush toilets and septic tanks. It is estimated that only about 12% of urban households are connected to the sewer system and wastewater treatment is virtually non-existent. Almost all the wastewater is discharged into nearby rivers without any treatment. The total wastewater produced in the country is estimated to be 370 million litres per day (MLD). The installed capacity of wastewater treatment plants is only 37 MLD (10% of total demand) and functioning wastewater treatment plants account for 17.5 MLD, or 5% of total demand (Nyachhyon, 2006).

The problem of wastewater management is particularly severe in Kathmandu Valley, which has five municipalities and is the largest urban centre in the country. In the 1980s four wastewater treatment plants were built in Kathmandu Valley, one in Sundarighat, Lalitpur to treat wastewater from the core areas of Kathmandu, another in Balkumari, Lalitpur to treat wastewater from the city of Lalitpur and one each in the Sallaghari and Hanumanghat areas of Bhaktapur. These treatment plants are based on simple lagoon systems, where wastewater is treated through natural processes such as sedimentation and biological degradation in a series of large lagoons. Although these plants are technically very simple with no mechanised parts, they are still not functioning well because of poor operation and maintenance and mismanagement. In 2002 another wastewater treatment plant that uses a more complicated oxidation ditch technology has been constructed at Guhyeshwori. Although this plant is partially functioning the cost of operation is very high and its sustainability is questionable.

Overall the wastewater generated by about two million residents in Kathmandu Valley has severely deteriorated the water quality in the Bagmati river, particularly in the urban stretches. This primarily affects the poor people who live near the river and are more exposed to the pollution.

The issues that arise from this prevailing position can be summarised as follows:

- As wastewater management is not a priority for most people or the government, simple and cost effective systems are necessary to ensure that they are managed in a sustainable manner.
- A simple and effective operation and maintenance system is essential for operating a wastewater treatment system.
- Centralised wastewater management systems are difficult to operate because of the difficulties in maintaining the long sewer networks and treatment plant.

In the late 1990s, in an attempt to try and deal with some of these difficulties, a new low-cost, low technology process was introduced, by which wetlands are constructed and wastewater treated in them. In this paper, the constructed wetlands process is presented, and its implementation in Nepal described. Some case studies provide particular details and then some commentary discusses the challenges involved and the way ahead.

Constructed wetland wastewater treatment system

Constructed Wetlands (CW) is a biological wastewater treatment technology designed to mimic processes found in natural wetland ecosystems. These systems use wetland plants, soils and their associated micro-organisms to remove contaminants from wastewater. Application of constructed wetlands for the treatment of municipal, industrial and agricultural wastewater as well as storm water started in the 1950s and they have been used in different configurations, scales and designs. CWs are receiving increasing worldwide attention for wastewater treatment and recycling due to the following major advantages:

- use of natural processes
- simple construction (can be constructed with local materials)
- simple operation and maintenance
- cost-effectiveness (low construction and operation costs)
- process stability.

Research studies have shown that wetland systems have great potential in controlling water pollution from domestic, industrial and non-point source contaminants. As it has been widely recognised as a simple, effective, reliable and economical technology compared to several other conventional systems, it can be a useful technology for developing countries.

There are various types of constructed wetland systems for treating wastewater based on the type of plants used, type of media used and flow dynamics. The most common type of constructed wetland system used in Nepal is the sub-surface flow system, which is also known as the Reed Bed Treatment System (RBTS). The basic features of

RBTS include a bed of uniformly graded sand or gravel with plants such as reeds growing on it. The most common type of plant used in Nepal is *Phragmites karka*. The depth of media is typically 0.3-0.6 m. Wastewater is evenly distributed on the bed and flows through it either horizontally or vertically. 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. As RBTS uses simple natural processes, it is effective yet inexpensive and simple to operate.

As noted above, the RBTS can be of two types: vertical flow (VF), where the wastewater flows

FIGURE 1 Horizontal flow constructed wetland

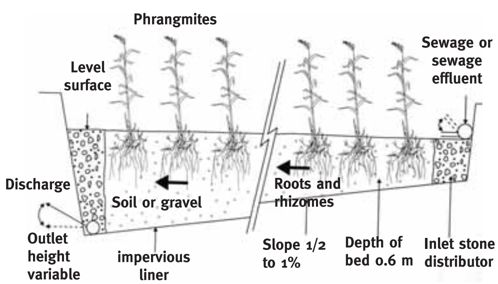
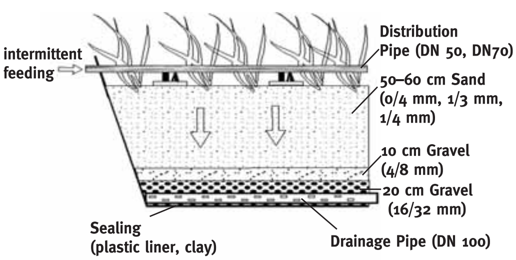


FIGURE 2 Vertical flow constructed wetland



vertically from the top to the bottom of the bed, and horizontal flow (HF), where the wastewater flows from one end of the bed to another. VF beds are fed intermittently in a large batch flooding the entire surface. After a while the bed drains completely free, allowing air to refill the bed. This kind of feeding leads to good oxygen transfer and hence better removal of pollutants. VF systems also require less land area (1-2 m^2/person) than HF systems, which need 5-10 m^2/person for secondary treatment. A typical VF system can

TABLE 1 Pollutant removal mechanisms in constructed wetlands

Wastewater constituents	Removal mechanism
Suspended solids	Sedimentation
	Filtration
Soluble organics	Aerobic microbial degradation
	Anaerobic microbial degradation
Phosphorous	Matrix sorption
	Plant uptake
Nitrogen	Ammonification followed by microbial nitrification
	Denitrification
	Plant uptake
	Matrix adsorption
	Ammonia volatilisation (mostly in SF system)
Metals	Adsorption and cation exchange
	Complexation
	Precipitation
	Plant uptake
	Microbial oxidation/reduction
Pathogens	Sedimentation
	Filtration
	Natural die-off
	Predation
	UV irradiation (SF system)
	Excretion of antibiotics from roots of macrophytes

Source: Cooper et al., 1996

remove the BOD5[1] of up to 96%; the HF system can remove only up to 65%. In recent years, a combination of the two (hybrid system) has become popular due to the higher efficiency of organic removal.

Constructed wetlands remove pollutants from wastewater through various physical, chemical and biological mechanisms. Some of the main pollutant removal mechanisms in constructed wetlands are presented in Table 1.

Constructed wetlands in Nepal

In Nepal, the Environment and Public Health Organisation (ENPHO) introduced CW for wastewater treatment in 1997 by constructing the first plant at Dhulikhel Hospital. Since then, the interest in this technology has been growing and more than a dozen constructed wetlands have been established for various applications such as the treatment of hospital wastewater, grey water, septage, landfill leachate, institutional wastewater and municipal wastewater. The first constructed wetland treatment plant in Dhulikhel was designed to treat 10 m^3/day of wastewater but it is successfully treating more than four times that amount.

Satisfied with the performance of the treatment plant, the hospital is now expanding the capacity of the plant. Recently, ENPHO with support from the Asian Development Bank (ADB), UNHABITAT, WaterAid Nepal, Madhyapur Thimi Municipality and the local people have established the first community-based wastewater treatment system in Nepal using this technology. The Urban Environment Improvement Project (UEIP) which is being implemented in eight urban centres with the

TABLE 2 Constructed Wetlands in Nepal

SN	Location	Type of Wastewater	Treatment Capacity
1	Dhulikhel Hospital	Hospital	Designed for 10 m3/day but treating 40 m3/day
2	Private house at Dallu	Grey water	0.5 m3/day
3	Kathmandu Metropolitan City	Septage	40 m3/day
4	Malpi International School	Institutional	25 m3/day
5	Sushma Koirala Memorial Plastic & Reconstructive Surgery Hospital	Hospital	15 m3/day
6	Kathmandu University	Institutional	40 m3/day
7	Staff Quarter of Middle Marshyangdi Hydro Electric Power Station	Domestic	26 m3/day
8	ENPHO Laboratory	Domestic and laboratory	1 m3/day
9	Kapan Monastery	Institutional	17 m3/day
10	Septage and Landfill leachate treatment plant	Septage and landfill leachate	Septage: 75 m3 and Leachate: 40 m3
11	Sunga	Municipal	25 m3/day

TABLE 3 Treatment efficiency of constructed wetlands in Nepal

Location	TSS Removal Rate (%)	BOD5 Removal Rate (%)	COD Removal Rate (%)	NH4 Removal Rate
Dhulikhel Hospital	98.6	98.9	83.7	57
Dallu House	98.6	99.5	96.8	97
Malpi School	99.1	99.5	99.5	98
SKM Hospital	98.1	99.2	95.4	98
Kathmandu University	97.9	98.9	99.1	99
ENPHO	92.1	99.7	97.8	91

Source: Shrestha et.al., 2003

[1] Microorganisms placed in contact with organic material will utilize it as a food source. In this utilization, the organic matter will eventually be oxidized to stable end products like carbon dioxide (CO_2) and water. The amount of oxygen used in this process is called the Biochemical Oxygen Demand and is considered to be a measure of the organic content of the waste.

assistance ADB is now in the process of constructing 18 more plants in these towns. A list of operating CWs in Nepal is given in Table 2.

In general, the performance of the CWs has been excellent. Regular monitoring of the systems shows high pollutant removal efficiency achieving close to 100% removal of total coliforms and organic pollutants. The pollutant removal rates in six different constructed wetlands are shown in Table 3.

Challenges

The experience with constructed wetlands over the last decade has clearly shown that this simple and cost effective system can be used to treat various types of wastewater ranging from grey water to leachate and septage. However, in spite of the enormous potential for the use of CW for wastewater treatment, there are some challenges in the promotion of this technology in Nepal, which are as follows:

- Due to the lack of awareness of CW technology, it is often difficult to convince people that it will work
- Although the cost of the technology is relatively low, it is still difficult to convince people to invest in a treatment plant instead of just discharging effluent into the river
- Although CW technology uses locally available materials, in some places specified types of sand and gravel or reads may not be readily available
- This is a low maintenance system, but people often think it is a no maintenance system. This sometimes leads to carelessness in taking care of simple operation and maintenance requirements such as checking for blockage in the pipes, harvesting the plants etc.

BOX 1 Dhulikhel Hospital establishes the first constructed wetland in Nepal

In 1997, Dhulikhel Hospital, a community-based hospital located in Dhulikhel Municipality, set up the first constructed wetland wastewater treatment system in Nepal to treat all the wastewater generated in the hospital and ensure that the people living around the hospital have access to clean treated water for irrigation. The system was designed by the Environment and Public Health Organisation (ENPHO) with technical support from the University of Natural Resources and Applied Life Science (BOKU), in Austria. As this was the first experiment with constructed wetlands in Nepal, the system was designed using fairly conservative assumptions and plenty of safety margin to ensure that the treated water would be of acceptable quality. As a result, although the volume of wastewater has increased more than fourfold, the treatment system is still operating effectively today. The treatment system was originally designed to treat 10 m^3 of wastewater per day, but it is currently treating about 40 m^3 per day as the capacity of the hospital has increased significantly over the past 10 years.

The constructed wetland at Dhulikhel Hospital has a sedimentation tank of 10 m3 capacity for pre-treatment followed by a horizontal flow bed then a vertical flow bed. The horizontal flow bed has a surface area of 140 m2 and is filled with 0.6 m sand and gravel. Similarly, the vertical flow bed has an area of 120 m2 and is filled with 1.05 m of sand and gravel. Both the beds are planted with local reeds of the species Phragmitis Karka. Initial tests done in 1997 showed that the plant was able to remove 98% of total suspended solids (TSS), 98% of BOD5, 96% of COD and 99.9% of total coliforms. It also removed 80% of the ammonia nitrogen and 54% of phosphate. Follow-up monitoring in 2003 showed that the plant was still removing 96% of BOD5 and 93% of TSS and COD.

The Hospital as well as the local people are very satisfied with the performance of the treatment system and the system has become a showpiece for the Hospital. Many researchers, students, journalists and other people regularly visit the Hospital to see the constructed wetland in action and learn from it. The Hospital is now in the process of expanding the system.

BOX 2 Greywater recycling at the household level using constructed wetland

Dr Roshan Raj Shrestha's family has a simple house built on about 40 m2 of land in Dallu, ward 15 of Kathmandu Metropolitan City. At first glance, the house does not look much different from the other houses in the neighbourhood. But it is very special because it is the first house in Nepal that treats and recycles its waste water to reduce water consumption as well as water pollution. In 1998, Dr Shrestha, who pioneered the use of Constructed Wetlands in Nepal, demonstrated how this technology could be applied to treat grey water at the household level, significantly reducing water demand and water pollution in a cost effective manner. In a city where the water demand is more than twice the supply and the discharge of untreated wastewater has significantly deteriorated the local rivers, this system has demonstrated how each family can make a difference.

The system consists of a 0.5 m3 water tank that has been converted into a settlement tank followed by a feeding tank and a small vertical flow reed bed with an area of only 6 m2. The system is good enough to treat all the grey water generated in the house with seven members and the treated water is used for non-consumptive uses such as flushing, gardening and washing. Tests done on the treated water showed that the system was able to remove 97% of the TSS, 98% of the BOD5, 98% of ammonia nitrogen and 99.9% of the total coliform. Dr Shrestha points out that the system required an investment of only about Rs. 35,000 (US$500) and the family is able to save about 400 litres of water per day.

BOX 3 Community-based wastewater management

Located in Madhyapur Thimi Municipality, Sunga Tole is the owner of the first community-based wastewater treatment plant in Nepal. Madhyapur Thimi is an old Newar community in the Kathmandu Valley, which is believed to have been settled in the 7th century. Situated on elevated land area at an altitude of 1325 m, the municipality covers a total area of 11.47 sq km and had a population of 47,751 in 2001. As the town was designated as a municipality only in 1996, major infrastructure developments like the sewerage system, water supply and road network are all still in the planning phase. Sanitation improvement is one of the most urgent issues the city needs to address, with more than 50% of the population still lacking proper sanitation facilities. Though a part of the municipality was connected to sewers in the 1990s and the wastewater was supposed to be treated through oxidation ponds the work remained incomplete because of a lack of funds.

At the request of the Municipality, in 2005, ENPHO, with support from ADB, UNHABITAT and WaterAid Nepal, initiated the construction of a community-based wastewater treatment plant at Siddhikali, where there was an outfall of a large sewer line and wasteland. However, after the construction began, a few people raised objections to the plant saying that it would pollute the local area. Even though a lot of effort was made to convince the local people and they were taken on observation visits to existing treatment plants, they refused to allow the construction to proceed. This meant that, although most of the local people supported the project, the objections of a few led to the failure of the initiative in Siddhikali, thus demonstrating the need for extensive community mobilisation.

Although disappointed by the initial setback, ENPHO and the municipality were delighted when the people of Sunga invited them to build the treatment plant in their neighbourhood instead. With the support of the local community, a new system was soon designed and built on steep terrain, which was previously a waste dumping site next to a school at Sunga. Now the site has a beautiful garden and a model treatment plant that provides a learning ground for students as well as professionals.

The constructed wetland at Sunga consists of a coarse screen and a grit chamber for preliminary treatment, a 42 m3 anaerobic baffle reactor (ABR) for primary treatment, horizontal flow followed by vertical flow reed beds for secondary treatment and two sludge drying beds for treating sludge. The total area of the constructed wetland is 375 m2. The treatment plant has a capacity to treat wastewater from 200 households, but it is currently treating wastewater from 80 households. The plant receives an average daily flow of 10 m3 of very high-strength wastewater (average BOD5 of raw wastewater is 1,775 mg/l). Monitoring of the performance of the system over its first year of operation shows that it removes organic pollutants highly efficiently (up to 98% TSS, 97% BOD5 and 96% COD). It was also found that the ABR was very effective in removing organic pollutants and could remove up to 74% TSS, 77% BOD5 and 77% COD (Singh et al., 2007).

The total cost of the treatment plant was Rs. 2.5 million and the municipality has agreed to provide Rs. 50,000 per year for operation and maintenance costs.

The total construction cost of the wetland amounted to NRs. 1,800,000 (US$ 26,000) at NRs. 2,900 (US$ 40) per m^2 of the wetland. The average O&M cost of the wetland is about NRs. 20,000 (US$ 290) per year.

BOX 4 Treatment of landfill leachate and septage

Leachate from landfill sites and septage from septic tanks are known to have very high concentrations of pollutants. As more and more cities construct landfills to manage their waste, there is a need to treat the leachate they generate. Often a simple pond is constructed at the bottom of the landfill to collect the leachate, which is then either recirculated back into the landfill, as in the case of the Sisdol Landfill in Kathmandu, treated or sent directly to the river. The experience from Sisdol shows that recirculation has not been effective in treating the landfill and direct discharge in the river can cause significant pollution downstream.

Septic tanks have been widely promoted as a means of on-site sanitation. In urban areas, many houses or institutions have septic tanks to partially treat the wastewater they generate. But these have to be periodically cleaned, which generates large quantities of highly concentrated faecal sludge or septage. Several municipalities and small private companies operate septic tank cleaning services. However, in the absence of treatment systems, the highly contaminated sludge is simply dumped in rivers, resulting in heavy pollution.

Pokhara Sub-Metropolitan City is a major tourist hub in western Nepal. The city is spread over an area of 55 sq. km. and had a population of 156,312 in 2001. In 2003, the Asian Development Bank supported Pokhara Environmental Improvement Programme to build a sanitary landfill site for the city as part of the Second Tourism Infrastructure Development Project. There was a need for a simple and cost effective system for treating the leachate as well as the sludge produced by cleaning of septic tanks in the city. It was estimated that the city generated 12,000 m3 of faecal sludge and 15,600 m3 of municipal waste every year, all of which would be collected and brought to the site. In response, a special wetland was built at the site which consisted of seven sludge drying beds occupying a total area of 1645 m2, where the faecal sludge is initially treated. Each day, sludge is spread on a separate sludge drying bed, resulting in a weekly feeding cycle. The dry sludge is removed and composed while the leachate from the sludge drying beds, as well as the leachate from the landfill, is fed into a feeding tank and then to two compartmental horizontal flow and four compartmental vertical flow constructed wetlands. The plant is designed to treat 35 m3 of septage and 40 m3 of landfill leachate per day.

The treatment plant at Pokhara is the largest constructed wetland in Nepal and it was built at a cost of Rs. 6 million (US$ 85,700). The effectiveness of the treatment plant has not yet been monitored as it is still not fully operational. However, as experiences from other countries have shown that constructed wetlands can be used to treat faecal sludge, the treatment plant built in Pokhara can be a model for other cities if it is operated properly.

- Wastewater treatment is not a priority for city governments, private industrialists or institutions, due to the lack of strong legislation and standards.

The way ahead

The following steps should be taken to further promote decentralised wastewater management through constructed wetlands:

- As this technology is still relatively new, there is need for continuous research and development to test the viability of this system under various conditions, including applicability for different types of wastewater, effectiveness under different climatic conditions, and the use of different materials and plants. The performance of existing constructed wetlands should be carefully monitored and additional research is required to optimise design and minimise construction cost.
- Pilot projects should be conducted to experiment with the use of this technology for industrial sites that produce wastewater with a high organic content, such as slaughterhouses, dairies, breweries and food processing industries.
- Although constructed wetlands are low maintenance systems people often think they are no maintenance system, resulting in poor performance due to simple problems such as clogging of pipes. Therefore, all systems need to be regularly monitored and proper systems for operation and maintenance should be established.
- Local governments, as well as international organisations involved in the water and wastewater sector, should promote this technology by building local capacity and scaling up its application.
- Professionals and organisations involved in promoting CW technology should be given opportunities to conduct experiments, improve their skills, network with one another and disseminate their findings.

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