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Toward a Beneficial Sanitation

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Abstract

Good sanitation for all is a major social and political challenge. Infrastructure for sanitation expanded in the last two centuries entailing a highly performing but costly production system. Possibilities of cost-saving along with social benefits through constructed wetland technologies are discussed with particular attention to the vertical flow technology, which is a cost-effective option based on experiences in the Netherlands. Cost-saving and income generating actions are presented based on examples across the world and brainstorming technique.

Keywords: *sanitation, constructed wetland, costs, income*

Introduction

Sanitation is a production system to prevent health risks related to polluted water (e.g. diarrhea, cholera, typhoid, hepatitis), as well as to foster good environment for human needs (e.g. leisure, tourism, drinking water reserve) and healthy ecosystems (e.g. rivers, wetlands, mangroves). This system transports and treats pollution from household toilets (called black water), kitchens and showers wastewater (called grey water), various suspended and dissolved compounds from industries, as well as water from rainfalls with run-off from agriculture, roads, landfills and so on (called storm water). For many people sanitation is an obvious part of urban life largely invisible after flushing toilet or sink because the network of underground pipes (called sewage) transports pollutants far away out of cities to a visible factory with huge concrete basins (called wastewater treatment plant); open sewage and treatment exist but these are old fashion. Aside a few professionals not many care about this system, unless heavy rainfall causes that its inner erupts to cover streets with stinky silt followed by warnings about threats for public health.

Politicians do mind sanitation. Their concern is primarily the huge expenditure because sanitation is often the third largest municipal bill after education and roads. The latter are important to gain votes in elections, the former hardly matters for this purpose. Hence, development of modern sanitation is rarely raised by the local politics. It is usually imposed on municipalities by a regional or national authority. A modern sanitation in a community of 100 000 citizens in an OECD country would typically involve a sequence of annual investments during a few decades totaling about USD 200 million, which is generally subsidized by the authority. This investment would cause yearly USD 15 - 20 million communal expenditures usually covered by fees paid by the citizens and some subsidies from the regional and national authorities (Krozer et al, 2009). This policy is found in many countries but it is uneasy to ask households a few hundred dollars payment without a tangible compensation due to income generation, which bring slow-down in sanitation development, as well as cost-saving and performance-reduction of the existing ones entailing corrupt, leaking pipes and obsolete water treatment is many countries. (Krozer et al, 2013). The cost of modern sanitation is a headache of all decision makers, politicians and individuals, particularly of those that cannot pay the bill, but when the modern sanitation is imposed on a community it is poorly maintained whereby pollutants flow untreated into water and soil. How to foster the modern sanitation but avoid high cost is a major global issue.

Hence, development of sanitation progresses slowly. It covered only 40% of the global population in 1990s, though it is more than 90% in the OECD countries, and it expanded in the last few decades to cover about 63% of the global population in 2010, albeit it is only 30% in the sub Saharan Africa, around 60% in Asia, up to 80% in Latin America. Mostly urban areas are served, whereas 55% of rural population lacks sanitation. Slums are rarely sanitized, whereas middleclass is served albeit full costs are rarely paid. Public policy also matters, e.g. Sri Lanka has more sanitation than twice richer Mexico (UNDP, 2006; WHO/UNICEF, 2012). Whether, the sanitation performance has progressed as much as the quantitative suggest can be disputed. Policies focus on low costs. Studies for the UN to underpin this progress envisaged that 2.1 billion people that lack sanitation can be served through USD 200 – 260 investments per person entailing USD 9 - 15 annual costs (USD 0.15 – 0.2 per cubic meter wastewater). This would be twice to five times lower cost than the social benefits due to health, productivity and so on (Hutton and Haler, 2004, Haller et al, 2007; Hutton and Batram, 2013). However, the installations at that low cost do hardly any more than transport excretes away from houses and dilute pollution in a neighbouring water body. Bringing up to standard modern sanitation in the urban and rural areas with pollution reduction and good maintenance of installation, which is the "Achilles heel" of sanitation, could be up to 10 times costlier. This is already experienced in the countries with modern sanitation. Doing things half way risks a cost but low performance entailing higher social costs after a while.

An alternative to less cost at lower performance is to innovate, which means raising investments for a novel solution. In this paper we discuss possibilities of a radical innovation in the modern sanitation through combination of helophytes filters on constructed wetlands with value adding services for water and land reuses. This can provide a cost-effective or even socially net income-generating breakthrough when it combines low-maintenance urban and rural equipment with income generation services. The aim of this paper is underpin a possibility of sanitation that brings private and social benefits. Firstly, the presently dominating technological system is presented to point out main challenges. Thereafter, the construction and use of wetlands is discussed, particularly the vertical flow technology. Then, possibilities of cost saving and income-generating services are reviewed with results of brainstorm about such services. Finally, we conclude about opportunities for this innovation.

1. Sanitation

Is modern sanitation cost-effective? Far reaching effects are achieved with the sewage and wastewater treatment, indeed. When sewage constructions emerged shortly after the French revolution (1789) in Paris they substituted vaults and cesspools under houses filled with chemically treated wastewater that soaked into ground or were brought away. A privy on backyard was rare; a septic tank is invented only late 1800s. Sewage decreased dramatically the polluted water-born epidemics. Whenever the modern sanitation entered these epidemics nearly vanished. This can be considered the technological innovation for social health of past centuries. As usual, also this innovation met fierce opposition during many decades. This time, the houses owners were unwilling to pay a fee and the farmers claiming dry dung for soil enrichment amalgamated their interests into a force that obstructed this modernization in the UK, US and many other industrialized countries throughout the 1800s despite regular outbreak of cholera, typhoid and so on. Only by 1887 the Prefect of Paris, EugénePoubelle, was able to enforce sanitation with fees on the house owners. This policy disseminate during the subsequent economic expansions of 1910s - 1920s in the US and 1950s - 1960s in Europe and Japan, and only in the last two decades to many other countries (Beder, 1990; Rockefeller, 1997; Burian et al, 2000, Paris project 2013).[1]

Throughout the last century the sanitation system is elongated aiming to improve the health conditions in remote areas and to treat the growing pollution. Sewage connected morehouseholds and businesses, including the dispersed ones in rural areas. The increasing connectivity exponentially enlarged the pipe length and the transport mileage entailing uses of stronger materials for pipes, more power for pumping and better monitoring of operations. Double sewage systems are envisaged to separate drainage from pollution flows and to cope with the polluted run-off during heavy rainfalls. At the end of the pipe the untreated pollution discharge into environment is widelyprohibited albeit it often occurs because theleaks from corrupted pipes and because municipalities do not install wastewater treatment plants. Nevertheless, a wastewater treatment emerged from early 1900s on evolving into a multistage process. The most basic treatment is mechanical separation and sedimentation of solids (1st stage), which is about a minimum pollution reduction. This is increasingly followed by the biological degradation under oxygen-free (anaerobic) and oxygen-enriched (aerobic) conditions (2nd stage) with various techniques. Some wastewater plants also treat specific pollutants, such as phosphate and heavy metals (3rd stage). An emerging stage is so called “polishing” which aims at the treatment of microbial, viral and hormonal pollutants. Residue that is accumulated in sewage (silt) and wastewater treatment plants (sludge), which consists of dust, sand, various minerals and organic matters, is collected and stored on farmland, or it is landfilled. This modern sanitation system has improved public health and ambient water quality a lot (Cooper, 2001).

The downside of the elongation is the cost increase. The sewage elongation, for example in the Netherlands between 1985 and 2004, caused the cost increase by 288% to USD 1 200 (€ 1 019) million in 2004, whereas the population has grown by only 12% (RIONED, 2013). This increase is mainly because more dispersed houses in the rural areas are connected.[2] In addition, the multistaged wastewater treatment caused more than a tenfold cost increase from about USD 0.1 per m^3 wastewater in the 1st stage to nearly USD 1.0 per m^3 for the 2nd and 3rd stages. The waste disposal costs also increased from a few dollars per ton to hundreds dollars per ton in cases of obligatory delivery to landfills, which is usual in the OECD countries. This made digestion for biogas production before the landfilling more attractive. The modern sanitation became capital intensive. It is estimated that 60% to 70% of the total life cycle costs in water supply and sanitation is depreciation on past investments, of this 50% - 60% for pipes and the remaining for treatment, of which 40% - 50% for construction and similar amount equipment, whereas the remaining 10% - 20% is know-how. In many countries, e.g. in the Netherlands, this depreciation is at the interest rates far below the commercial interest. Only 30% to 40% of the total life cycle cost is made up of variable costs, of which 70% is staff costs and the other 30% forchemicals, energy, space and so on. Numerous incremental improvements are introduced and under development to increase effects and reduce costs in a step but these hardly improve the overall system performance, even can deteriorate its cost-effectiveness (Krozer et al, 2009).

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[1] Until far into the 20th centurysanitation is consideredwork of outcasts (e.g. Dalits, BlacksandJews), e.g. in Cracow (Poland) Jewswereaccusedby farmers of steelingfertilizersthrough the canals.

[2] From 1997 to 2007 in the Netherlands, the cost of the cheapest sewage per household increased from the average 2 800 to 3 800 euro (USD 3 100 to 4 200), the most expensive one from 6 700 to 9 300 euro (USD 7 400 to 10 200). US replacing km sewage costs USD 0.15 to 0.2 mln (http://www.buzzle.com/articles/sewer-line-replacement-cost.html)

A consequence of high capital intensity is that decisions about sanitation create structures and equipment that stay many decades. Hence, the elongation unintentionally created a bck-in in water management because scarce finance and sink costs of past investments impede modernization and immobile constructions hinder international competition. Nevertheless, innovations in the system are necessary to serve large of the global population and ecosystems because only a minority can pay high costs of the elongated sanitation. An effective, cheap, even income generating sanitation could create interest in communities entailing spontaneous investments and maintenance.

2. Constructed wetlands

A radical innovation that reduces the costs of sanitation without compromising on its effects is through mimicry of processes on natural wetland. A sanitation option is constructed wetlands, which mimics working of the natural wetlands using macrophytes, such as water hyacinth, duckweed, cattail, bulrush, reed and others. This technology is, in theory, cost-effective compared to the conventional system. Firstly, sewage can be shortened because wastewater treatment, if it remains under the soil surface, can be located in vicinity of houses. Such location rapidly reduces the pipe lengths and power for transport. Secondly, the concrete constructions and aeration installation with large energy use at the conventional wastewater treatment can be avoided because micro-organisms bound to plants do most of thework. Thirdly, the maintenance is negligible because small pumps and plant cutting are needed. We donot elaborate on the constructions and operations of the constructed wetlands because several good manuals for this purpose can be found (e.g. Hydrik, 1998; Stantec, 1999; EPA, 1999; UN-HABITAT, 2008).

Instead of going into details of various constructed wetlands, we present experiences with the vertical flow constructed wetland filters in the Netherlands because thousands of such installations successfully. An increasing number of this technology operates in Scandinavia and the Netherlands to treat various pollution sources and scales, ranging from one household up to a few thousand households per installation, large industrial sites, farms, tourist sites, landfills and other pollution sources. Slower progress is found in emerging economies and developing countries that are situated in warm climates, which is more suitable for this type of technologies. The reason for this peculiar disparity we can only guess.

2,1 Construction

The construction phases of the vertical flow helophyte filter are shown on photographs of a filter at a school with nearly thousand pupils in the new housing district of the Culemborg town.

Photo serial 1. Construction of the Brinkvos water vertical flow helophyte filter at a school

Excavation 1 m deep | Foils, shells and lava | Clean sand filling | Drip pipes and reed

The construction proceeds in four phases (a) excavation of soil down to about 1 meter deep, (b) putting foils for soil protection, (c) putting layers of shells, gravel and clean sand for micro-organism activities, (d) putting pipes for drip irrigation under soil surface and sowing reed or another crop. The pictures do not show tanks needed for the sedimentation and primary degradation of household excretes. The filter after a few months is shown on the picture beneath taken from the school on the back toward a housing district on approximately 30 m distance from the filter. All construction can be done locally. Scaling and tuning of the filter to the location and pollution need know-how.

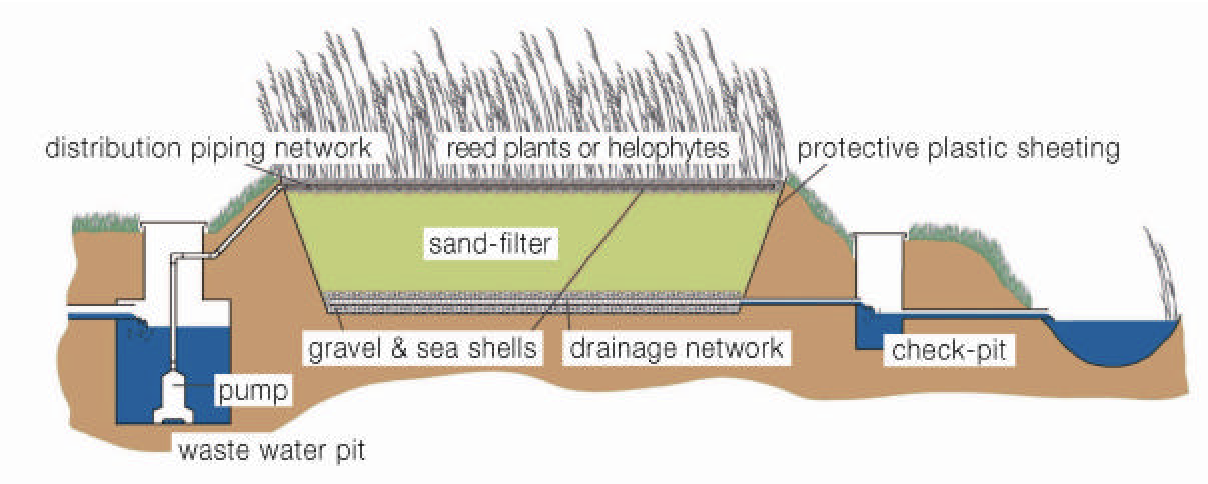
Photo 2 Grown helophyte filter

This approximately 400m^2 large filter treats excretes from the school and neighbouring 150 housing units. Reed is often used because it is cheap, annual, fast growing and frost resistant. It is also easy to sow. The perennial plants are also possible, e.g. Salix species. Experime nts with Cyperus and Miscanthidium in the warm climates show good results for the nitrate and phosphate pollution (Kyambade, 2004). We are not aware of cost-effective interbreedingexperiments.

2,2 Process

The main steps in the wastewater treatment process using the Brinkvos water vertical flow helophytes filter is presented in scheme 1. The process is continuous, safe and free of odours. It hardly uses energy, is nearly maintenance-free, flexible with respect to load peaks and climatic conditions, such as frost resistance. The technology is also scalable, it means one can start with a small scale and gradually increase to cover more pollution sources and units. All operations can be done locally with minor external technological support based on experiences.

Scheme 1. Operation of the Brinkvos water vertical flow helophytes filter



Before treatment wastewater is allowed for sedimentation in a tank, which scale depends on the inflow volume and pollution. From the tank, wastewater is pumped on top of the filter bed and evenly spread through pipes under soil surface to drip into the filter. The pumps that bring wastewater on top of the filter bed work automatic and monitoring units have failure alarm incorporated into electronic control system. The protective, durable plastic sheets at the filter base separate pollution from the surrounding soil. Micro-organisms in several layers of sand, seashells and gravel degrade the biological matter, as well as absorb minerals such as nitrates and phosphates. The wastewater distribution piping network on the top and a purified water drainage network at the bottom enable continuous flow through the filter. The filter is planted with reeds or other plants whose root zone can reach deep into the filter to foster organic activities that purify the waste water. The effluent is pumped into a check-pit; and eventually reused, infiltrated or dumped into a surface water body. Table 1 shows results as certified by the Dutch water certification body (KIWA). The performance is excellent. It exceeds by far the certification criteria in the Netherlands that has among the most stringent criteria for wastewater treatment in the world.

Table 1. Certification data for the BrinkVos vertical flow helophytes filter in mg/l; it is the highest possible, so called IIIB, certification

parameter	Certification criteria	Realized average
COD	100	17
BOD	20	3
N - Total	30	18.2
NH_4-N	2	0.4
P – Total	3	0.09
TSS (suspended solids)	30	2.2

In addition to a few thousands units for treatment of household wastewater mentioned above various specialties are treated, such as: water run-off of roads with high contamination, chlorinated compounds and hydrocarbons in soil (e.g.: benzene reduced from 300 µg/l to less than 1 µg/l), grey water reuse in agricultural, industrial or secondary (non-potable) household use, addition purification of effluent from wastewater treatment plants (so called “polishing”) and others. The experiences are that this system operates successfully and nearly maintenance-free throughout minimum three decades.

The main disadvantage of all types of the constructed wetlands (as well as other types of natural treatment) is their high space use. The space use that is necessary for adequate wastewater treatment is derived from the BOD removal kinetics, after Arceivala and Asolekar (2008:283)

?? ? ???^{???} (1)

for

? ? ???? (2)

or

? ? (? ??? ??? ?? ???) / (?????) (3)

Where area bed area in m^2, A, is the logarithmic function of the average flow in m^3/day, Q, inlet 5 day-BOD in mg/l, C_0, and outlet BOD_5 in mg/l, and reaction constant per day ?????.

The K factor, estimated empirically, varies from 0.067 in cold and wet UK and 0.083 in Denmark up to 0.17 in warm Bangalore, India. In general, the K factor is considered a logarithmic function of temperature, whereby up to twice higher values are assumed in warm humid countries, whereby the horizontal constructed wetlands would require 1 – 2 m^2 per person equivalent wastewater and the vertical ones would need 0.8 – 1.5 m^2 per person equivalent (UN-HABITAT, p.19). Hence, less stringent performance criteria and warmer climates exponentially reduce the space.

Neverthelss, even the most effective constructed wetland in a warm climate is several times more land consuming that the conventional multistage systems, even more so compared to the denser bio-membranes installations.[3] The large footprint of the constructed wetland is an important disadvantage because land is a valuable asset particularly in densely populated areas where good sanitation is pressing. This disadvantage pushes this clean production into margin of the sanitation market. As long the ecological footprint, the area needed to absorb human pressures on environment, is notexpressed in market prices constructed wetlands loose competition with the compact, though costly and polluting conventional wastewater treatment. Innovations in constructed wetlands are necessary.

[3] A modern multistage wastewater treatment plant uses 0.11 m2 per person (50 000 m2 for 430 000 equivalents). http://delfluent.nl/plant/awzi-houtrust/

3. Income generation

What are innovatio n options for the constructed wetlands? We envisage three innovations strategies for a constructed wetland: making it more effective, making it cost - saving and a adding value one. Helping nature can increase effects. Above all, pollution reduction of constructed wetlands would double when disseminates in the warm countries whilst they are present mainly in the temperate climates of Europe and America. Also helping microorganisms in soil with biodegradation through aeration can help. Nature under and on soil surface can also get a hand through selection and breeding of plants that enable more biological activity in oxygen-rich conditions. Several cost saving innovations are also possible, such as the substitution of septic tanks and electric pumps through mechanical dispersion because these two are the largest cost factors of the vertical constructed wetlands, aside the labour. The effect-increasing and cost-reducing help but they presumably cannot approach the footprint of the conventional wastewater treatment plants. Another approach is needed, as well

Adding value to the constructed wetlands could compensate the high area use and create the communities' interests. The starting point in this approach is the multifunctional construction: biological degradation under the surface and value adding ecosystem service on top of the filter, whereby these services do not interact with pollutants and interfere with biodegradation under the soil. Attempts to add such services are made. Herewith, we wish to mention trailblazing works of Wastewater Gardens derived from experiments on development of artificial in closed ecosystems (Biosphere 2). Beneath, we present pictures and results of experiments in Mexico as an example of services in the tourist areas. For details we refer to Nelson et al web and Nelson et al., 2006.

Table 2 Wastewater treatment performace of the wastewater gardens, after Nelson et al web and Nelson et al. (2006)

Parameter	In Septic tank mg/l	Out Discharge mg/l (Dutch norms)	Removal%	Loading kg/ha/d
BOD	145	17.6 (20)	87.9	32.1
Total Phosphorus	8.05	1.9 (3)	76.4	1.7
Total Nitrogen	47.6	10.0 (30)	79	10.3
Total Susp. Solids	69.9	38.9 (30)	44.4	
Coliform bacteria	49×10^6	2.2×10^3	99.8	

Using web we found 55 cases of the value-adding and cost-saving services integrated into constructed wetlands, which is only a top of ice-berg because many projects do not explicate such services. About two third of all identified projects are in the rural areas. About two-third are the horizontal constructed wetlands; in the urban areas are mainly the vertical ones. Most constructed wetlands serve households but there are also tourist centers, institutions, run-off, effluents and others. The additional services are mainly water reuse (16x) but there are also training, education and training centers, recreational areas, biodiversity fields, landscaping, ecosystem resorting, fish ponds, parks, social inclusion projects

and so on. Various benefits are generated such as better effluent treatment and more groundwater protection, diversity vegetation for parks and gardens, nature experience through footpaths and walk trails, arts with wood works, fishing, rain harvesting and so on. However, only a few payable services are found, such as biofuel, entry to diversity gardens, recreation, fishing, and boating, wood carving and water storage and use in dry areas. Unfortunately, not many projects pay attention to the value-adding and cost-saving services. Social cost - benefit assessments of the constructed wetlands services are found but these address the non-users benefits derived from values of the natural wetlands, which do not generate income. Nevertheless, the potential benefits can compensate the costs.
Beneath, table 3 is presented with hypothetical costs and benefits based on real Dutch data.

Table 3 Indication of costs and benefits in 1000 euro based on the Dutch data

filter types	filter for household black water	wetland for industrial water
Persons	400	
water flow in m3/day	80	2,000
filter area in m2	1,500	8,000
Investment		
construction of the filter	120	100
development of the services	20	10
annual costs (high assumptions)		
capital (i=10% , t=10)	(21)	(18)
manpower for maintenance and controls	(13)	(12)
land coverage (opportunity cost)	(15)	(40)
energy for the pump	(1)	(5)
Total	(49)	(75)
annual benefits (lowest assumptions)		
saved effluent fees	33	98
saved water use	9	32
leisure (option value € 10/m2)	23	
biogas and CO2 storage	1	
Total	66	131
Benefit	17	56
payback in years	2.1	0.8

The cost-saving and income-generating services can outweigh the costs when all services are included. Herewith, distinction should be made between the cost-saving services due to lower fees and water reuse and the income-generating ones on top of the wetland, such as leisure, education, and so on. In the countries with subsidized effluent fees and water use, which is found in most countries in the world, the latter are even more important for the communities' net benefit than the cost saving activities.

A more systematic elaboration on the potentially value adding services in addition to effective wastewater treatment through the constructed wetlands could be done through brainstorming. Such brainstorming is organized on 15th February, 2013, with the business development group Enviu. The aim was to explore possibilities for a strong connection between the filter and community because it would foster various activities in addition to the wastewater treatment and make filter operations sustainable. After brief introduction of this issue, the participating twenty people divided into three groups discussed novel activities and risks. Not many risks are perceived aside the possibility that people use the effluent after treatment for drinking even though it is not recommendable.
The ideas for the additional activities are shown in Table 4.

Table 4 Ideas for linking a constructed wetlands with a neighbouring community

Wastewater filter attribute	Activities	Specifications
Space use	Playground	School projects, Insight into filtering processes
	Parks	Biodiversity, Zoo
	Gardening	Flowers, feed crops
	Ceremonial ground	Spreading ashes, burial
	Adding solar power	Recharging mobiles, sanitation facilities
Roof tops	Urban gardening	
	Climate controls	
Protecting environment	Soil retention	
	Water retention	
Reuse water	Irrigation	
	Fishing	
	Washing	
	Swimming	Hygiene facilities

Most additional activities exploit space use. Several conventional uses are playgrounds, parks, gardens. The unconventional ones are: creating an area for religious or ceremonial purposes, such as spreading ashes, and addition of photovoltaic energy to create a phone recharge spot, and a facility for hygiene and washing. Unconventional options are also filters on roofs for gardening and climate control. More conventional are environment protection and reuse of effluent for technical water. Whether these ideas come through and generate income is to be seen based on experiments.

4. Conclusions

Modern sanitation is an effective production system for public health and environmental quality but its cost expand as the system elongates to serve more people with sewage and to tackle growing pollution through multistage wastewater treatment plants. Financing it is under stress because communities and individuals have little individual interests to attract private investments and the public budget receives less income but it has more priorities. Cost-savings undermine performance because of leaking sewage and obsolete treatment equipment, whereas incremental changes in one step hardly help but can raise costs in this production system.

Innovations in the system are possible through the constructed wetlands that mimic the natural processes on wetlands. This enables to shorten the sanitation system through the decentralization and substitute installations through natural treatment. These actions reduce the costs without sacrificing the high performance of modern sanitation. The drawback of this innovation is high space use in comparison with the conventional technologies. The space use can be somewhat reduced through enhancing of the biological processes and some costs can be saved through substitution of the costly production factors but these improvements of the constructed wetlands are insufficient to compete with the conventional sanitation technologies. More innovations are needed. A particularly promising one is adding services that create value and cost saving on top of the constructed wetlands. The cost-saving services are linked to the water reusing and decreasing effluent fees. The value addition can be reached through training, education and training centers, recreational areas, biodiversity fields, landscaping, ecosystem resorting, fish ponds, parks, social inclusion projects and so on. Some of these services could generate sufficient private income to recover the investment costs of constructed wetlands within a reasonable payback time. The innovative constructed wetland enable to meet demands for sanitation in the communities that cannot afford modern sanitation.

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