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Review Article

Advance in Environmental Waste Management & Recycling

Value Adding Innovations in Sanitation

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Abstract

Conventional sanitation based on long transport of wastewater in sewage and multistage wastewater treatment prevents health and environmental impacts but it is costly. Two innovations in sanitation, which comply with high health and environmental standards and reduce costs are presented. A social innovation led by a farmers' association reuses effluent on a regional scale. After municipal wastewater treatment effluents are transported to reservoirs for additional biodegradation and reuse for irrigation. About 30% of the annual costs are saved compared to the conventional sanitation but regulations and organizational challenges impede dissemination of this systems. A technological innovation led by social entrepreneurs and non-governmental organizations refers to the decentralized sanitation with biodigesters and constructed wetlands. A vertical flow helophyte system, certified for the highest health and environmental standards, is used for sanitation of a few million person equivalents in households, services and industries. The costs are reduced by 40% compared to the conventional sanitation and can be beneficial when scale is large and co-benefits are attained but they need much space. The innovative citizen's initiatives can be encouraged given low institutional interest for innovative sanitation.

Keywords: Sanitation, Citizen's Initiatives, Costs, Benefits, Effluent Reuse, Constructed Wetland

Highlights

1. Conventional sanitation effectively prevents threats to public health and environmental qualities but is costly and energy consuming.
2. Cost saving effluent reuse can be achieved due to citizen's initiatives that organize cooperation between regional stakeholders.
3. Constructed wetland can meet highest sanitation standards and save costs due to valuable services.
4. Policies can generate beneficial sanitation when they encourage innovative citizens' initiatives.

Introduction

Water after consumption in businesses and households should be effectively collected and treated before discharge into environment in order to avoid cholera, dysentery and other diseases, and prevent environmental degradation by nitrification and hazardous compounds. The discharge after treatment, it means effluent, must comply with stringent regulatory standards. The stakeholders, technologies and regulations for that purpose constitute a system called sanitation. While the discharges of washing, cleaning and cooking wastewater, called 'grey water', need moderate treatment before the discharge of effluents, the urine and feces from households, as well as the organic matter and hazardous compounds from industries need advanced treatment before this 'black water' is safe for discharges. Herewith, it is focused on the black water because its sanitation unaffordable to many people. Social and technological innovations aiming to improve effects and reduce costs are addressed, whilst innovations are considered novel entrepreneurial activities.

Globally, about 320 km^3 municipal wastewater and nearly 640 km^3 industrial wastewater are discharged per year, which constitute about 8% and 16% of the total wastewater while the remaining volume is discharged by agriculture [1]. Access to an effective sanitation for all people is a global sustainable development goal (SDG) number 6. Though most municipal and industrial wastewater is collected in sewage it is often discharged into environment without sufficient treatment to prevent health and environmental risks. Nearly 40% of the global population, which is about 2.5 billion people, lack sanitation with an effective treatment [2]. The deficient sanitation causes that many more people suffer because the polluted water is not useful for irrigation, swimming, fishery and other beneficial activities, which is particularly pressing in the water-scarce areas [3-5]. The situation is somewhat better in the European Union (EU) where regulations prescribe the collection and biological treatment of wastewater in settlements larger than 2000 people [6]. Despite these regulatory demands, about 15% of the EU population, which is nearly 78 million, have no access to such sanitation; it is even 20% of all people in the southern and eastern European countries [7]. In addition, wastewater from the dispersed sources is not collected, neither treated even though the manure discharge on soil is a major cause of nutrification because the nitrates permeate through soil to groundwater and the phosphates wash out to surface water. Wash-out from roads and roofs is a major source of hazardous heavy metals in waterways. Hence, an effective sanitation is still far away even in the wealthy EU countries with stringent regulations.

High cost is the barrier implementation of the effective sanitation though studies commissioned by the World Health Organisation (WHO) suggest higher benefits than costs. The estimates indicate that high access to sanitation needs USD 200 – 260 (€ ≈ 1.3 USD) investment per person, which causes USD 9 - 15 annual costs per person because equipment is annually depreciated during many years, whilst the health benefits are about five times higher [8-10]. The studies argued that the present global expenditures of USD 115 billion a year should be increased by USD 25 billion in order to close the gap between low-income countries and high-income ones with respect to risks of water-borne diseases, excluding environmental qualities [11]. This argumentation that sanitation is affordable and beneficial in all countries can be a wishful thinking.

Experiences in the high-income countries show that the sanitation expenditures aiming to prevent diseases and environmental degradation are usually nearly ten times higher than those estimates. A city of 100 000 inhabitants needs typically about USD 100 million investment in sewage and treatment, which causes about USD 8 million annual capital costs that must be covered by more than USD 80 per person. The costs are usually covered by a fee per person equivalent paid by households and businesses. As the regulatory demands become more stringent in time because pollution increases the costs and fees increase. For example, in the Netherlands between 1985 and 2004 the population increase by 12% to 16 million people triggered 288% cost increase of sanitation to USD 1200 million a year because the dispersed settlements are connected and more effective treatment is implemented [12]. Although three times costlier sanitation causes similarly higher fees per person equivalent, innovations progress slowly because the past investments remain during decades at place whilst scrapping is costly and the regulators usually prescribe implementation of particular technologies without consideration of the innovative alternatives. The issue, therefore, is about how innovations for accessible and effective sanitation for all households and businesses can be encouraged.

While the national authorities set a regulatory framework, sanitation is usually governed by the municipalities, waterboards and other local authorities that have weak incentives for innovations because benefit from fees, which renders the idea about corrections of this policy failure by the citizens initiatives [13-15]. In line with the Ostrom (1990) ideas about the social governance of common goods, many scholars and activists advocate citizen's initiatives which are assumed adaptive to the local conditions due to local capabilities [16]. More 'grassroots, 'bottom-up', 'local initiatives', 'civil initiatives' and suchlike non-governmental activities are observed [15,17,18,]. Citizens address local issues, entrepreneurs create social enterprises and communities develop policies [19-24]. They expand because the citizens-led innovations can generate co-benefits meaning complementary public services across sectors; for example, care, health and education in community centers, or water transport, water supply and fire control due to clean water [25]. However, the citizens initiatives are not always welcomed by authorities because compete with the vested governance which undermines the regulatory power and income [26].

The innovative citizens' initiatives can save costs and generate co-benefits, due to additional services thereby enhance access to sanitation. Many experiments and demonstration projects aim at separation of wastewater streams in households, such as the separation of grey water from black water, urine from feces within black water, water-free urinals and biodegradation toilets for the concentration and recycling of minerals and energy generation from the organic matter. They are cost saving but dissemination stagnates because of necessary changes in housing and behavior of households and regulators. Innovations within the sanitation systems can be easier to scale up because do not need such behavioural changes. This paper presents two innovations within the sanitation system: a social innovation led by a farmers' association that created a regional sanitation system for reuse of effluents in Israel and a technological innovation led van social entrepreneurs and non-governmental organization focused on the decentralized wastewater treatment with plants. Each of them treated several million person equivalents during last decades within stringent standards and delivered valuable services with co-benefits. Their background and benefits are shown. Section 2 covers the conventional sanitation system, Section 3 the social innovation, Section 4 the technological innovation and Section 5 draws conclusions.

Conventional Sanitation

Vaults and cesspools still used in low-income countries and rural areas are increasingly replaced by the conventional sanitation systems with sewage for collection of discharges and a multistage treatment of wastewater far away from the pollution sources. This is a major innovation in the public health because prevents many water-borne epidemics with high children mortality [27].

Elongation

The conventional sanitation systems have emerged shortly after the French revolution in 1789 when gravity sewage replacement of vaults and cesspools has commenced. As it is often experienced in the innovating for common goods, sewage has also encountered fierce opposition of the vested interests. Wherever it was introduced in France, United Kingdom, United States and other countries, the landlords unwilling to pay a fee and farmers claiming faeces for soil enrichment amalgamated their interests for obstructions of sewage while strangers are often blamed for theft of dung, in particular, Jewish conspiracy was a popular gossip. The obstructions continued throughout the 1800s despite evident benefits to the public health. Only by 1887 the Prefect of Paris, Eugéne Poubelle, was able to enforce the construction of sewage based on fees which blazed trails for its dissemination in the United States, Europe and Japan during the economic upswings early 1900s until the 1st World War and during 1950s - 1960s after the 2nd World War [28-30]. Still in 1990s only about 40% of the global population was connected to sewage and 63% by 2010, about 30% in Africa, 60% in Asia, more than 80% in Latin America and 90% in high-income countries.

The dissemination of sewage evolves slowly. Given 1.4% annual average growth of the global population from 5.28 billion people in 1990 to 6.93 billion in 2010, the global access to sewage has grown faster because 3.9% annual average but slower than 5.6% income per person; apparently, other expenditures are prioritized. Sanitation also varies across social classes and countries. Globally, most urban settlements have sewage but rarely slums, whilst 55% of rural settlements lack sewage. Richer people are usually connected but rarely pay all costs, which impedes maintenance of pipes causing leaks [31,32]. Across countries, Sri Lanka as an example has more sanitation per person than twice richer per person Mexico. Several high income countries elongate sewage for the dispersed houses in rural areas and advocate double sewage for separation of drainage and slurry in order to avoid polluted run-off during heavy rainfalls. As the sewage elongates the transported distance expands, which requires longer pipes, stronger materials for the pipes, more powerful pumping, more booster stations, better maintenance and monitoring of operations. The costs increase.

Wastewater treatment emerged early 1900s when sediments in sewage (silt) is collected in basins at the end of pipes for sedimentation because discharges cloaked waterways. During the last century, the wastewater treatment plants grew into a multistage processing. Present minimum is the mechanical separation and sedimentation of solids in septic tanks or basins called 1st stage treatment. In addition, the biological degradation through digestion in oxygen-free conditions (anaerobic) is followed by the oxygen-enriched (aerobic) treatment of the organic matter (sludge), which is 2nd stage. Furthermore, nitrates, phosphate, heavy metals and other pollutants are increasingly bound and separated in the 3rd stage. Breaking microbial, viral and hormonal pollution emerges called the 'effluent polishing'. Effluents after the 2nd stage treatment are often permitted for the reuse in toilets, cleaning, gardening and other technical purposes but usually discharged into environment because primary water is often cheaper than the effluent reuse. The reuse in agriculture is strictly regulated with regards to contamination of foods and high salt concentration in effluents. Silt and sludge, which consists of mineral dust, sand and organic matters can be used for the soil enrichment, but presently, they are increasingly landfilled in the EU with regard to concentration of hazardous compounds, sometimes digested for the biogas winning and volume reduction before the landfilling.

Impacts

As the conventional sanitation system elongates because sewage covers more settlements and treatment evolvs into multistage processes the unit costs increase by more than tenfold; the unit cost or marginal costs is the total annual cost per treated volume. The unit cost of sanitation is about USD 0.1 per m^3 for sewage with 1st stage treatment and increases to more than USD 1.0 per m^3 for the 2nd stage, whilst sewage for the dispersed houses with 3rd stage treatment is twice costlier. A few dollars per ton sludge disposal on farmland increases to a few hundred dollars per ton for landfill, which renders economic digestion. For given volume, higher unit costs trigger higher fees which persist because nearly 70% of the unit costs are caused by the annual depreciations of investments during more than 30 years, and they increase if the effluent polishing and double sewage are added [12].

Sanitation also consumes much energy because large water volumes are processed. Globally, about 800 TWh is consumed in sanitation; for example, it is more than 620 TWh consumed by the aluminium industry that is considered energy-intensive. The global sanitation consumes about 3.6% of the global electricity; it is about 3.5% in the EU [6,33]. Energy-efficiency is about 0.4 kWh per m^3 per km sewage transport, which is usually transported 5 km or longer, plus 0.3 kWh per m^3 for the mechanical treatment up to 2.8 kWh per m^3 for the multi-stage treatment [34]. Since the access to sewage expands and regulatory demands for wastewater treatment increase the energy consumption grows exponentially.

The elongation of conventional sanitation has effectively improved public health and environmental qualities in the world, which is an important common good [35]. However, the system is costly and uses much energy whilst its dissemination evolves slowly because it is politically risky to ask for higher fees from individuals while benefits are obtained collectively. The institutional interests in the cost-saving innovations are also low because higher fees imply more incomes of authorities though citizens and communities seek solutions that save costs and deliver benefits.

Effluent Reuse

The farmers' association 'Palgey Ma'im' is a social innovation which created a new institution that links urban and rural settlements into the regional network for the wastewater treatment and effluent reuse. The economic perspective, herewith, adds to technical studies on this case [36-38]. Data and personal communications refer to the research by Sharon Hophmayer-Tokich [references 56-67].

Project

Given water scarcity in Israel, its 180 m3 water availability per person a year is below 500 m^3 defined as a water scarce country by the Global Water Forum, nearly 85% of all effluents are reused [39]. A cost-effective sanitation with effluent reuse is realized by the Palgey Ma'im in the Jezreel valley due to organizational changes rather than technologies [40]. Jezreel Valley is located in the Northern part of Israel on circa 380 km^2 fertile plain with 40,000 inhabitants in 31 small rural settlements and two urban settlements: Megiddo with circa 10,000 inhabitants and Afula with circa 40,000 inhabitants. The valley is surrounded by hills of Galilee to the north, Samaria to the south and Carmel to the west with 11 urban settlements, all smaller than 20,000 inhabitants except Nazareth with 60,000 inhabitants. A few water streams flow through the valley but the region has no local sources of potable water and receives water from the national water carrier [36].

Given the water scarcity most people in Israel have been connected to sewage shortly after establishment of the Statehood in 1948 but the wastewater treatment is largely neglected until 1990s though used for irrigation [41,42]. In the Jezreel Valley, urban settlements on hills discharged effluents by gravitation without treatment or after 1st stage treatment based on agreements with adjacent rural settlements about the reuse. Although the agreements were disputed actions were not needed as long as the urban settlements did not sense nuisance and disposed wastewater cheaply, whilst reuse in the rural settlements was hardly regulated (Ben Meir, personal communication, 21 February 2002). Moreover, the reservoirs for storage of rainwater, runoff water and local springs that were erected during 1970s deteriorated because unused due to cheap effluents (Sofer, Personal communication, 27 June 2014). However, after the outbreak of cholera early 1980s, the national authorities restricted the reuse to the technical crops as cotton and imposed standards for discharges by all settlements above 10 000 persons to maximum 20 mg/l Biological Oxygen Demand (BOD) and 30 mg/l Total Suspended Solids (TSS). These standards need 2nd stage wastewater treatment and a large national budget is focused on the biological wastewater treatment plants whilst other methods are rejected. When the municipalities faced higher costs of sanitation early 1990s, they demanded higher prices for effluents while farmers searched cheaper purchases. By the end of 1990s, quotas for the irrigation water are allocated among farmers and prices for the effluent are set with reference to that water price: effluents after 2nd stage 50% of that price, after 3rd stage 60% of it and higher quality 75% of it; But only after a few consecutive droughts and cuts in water allocation for irrigation the societal sense of urgency for action emerged because many farmers could not sustain and residents confronted high costs [43]. This sense of urgency invoked the farmers' association, Palgey Maim (Personal communications: Yshay, 8 August 2001; Ben Meir, 21 February 2002; Sofer, 27 June 2014).

Technically, this association links the wastewater treatment plants in urban settlements uphill to the distribution and reuse of effluents in rural settlements across the valley. The effluents flowing downhill are stored in the reservoirs during several days with additional biodegradation in the valley and distributed among farmers for the reuse as irrigation water. This system is developed in phases. Firstly, eight wastewater treatment plants are upgraded because aimed to meet the national standards, which is cheaper than the upgradation of each one separately. Secondly, 29 reservoirs in the valley are upgraded and 7 new ones are constructed. Third, 82 km pipeline is laid to connect the treatment plants and reservoirs, which can balance the quantity of effluents for reuse through overflow between these reservoirs and maintain sufficient quality through the retention time, which are monitored. It took more than ten years for the realization. The technical concept defined by Palgey Maim in cooperation with the Israeli Institute for Technology in 1989 is followed by field tests which confirmed the concept and enabled acquisition of permits for the start of execution in 1992. Then, wastewater treatment plants, additional reservoirs and pipelines were constructed during the subsequent decade, entailing numerous adaptations until present to cope with regulations, expansion of the urban settlements and agriculture; Personal communications: Ben Meir, 21 February 2002; Juaniko, 20 August 1998; Sofer, 27 June 2014). Figure 1 shows the sanitation system [37].

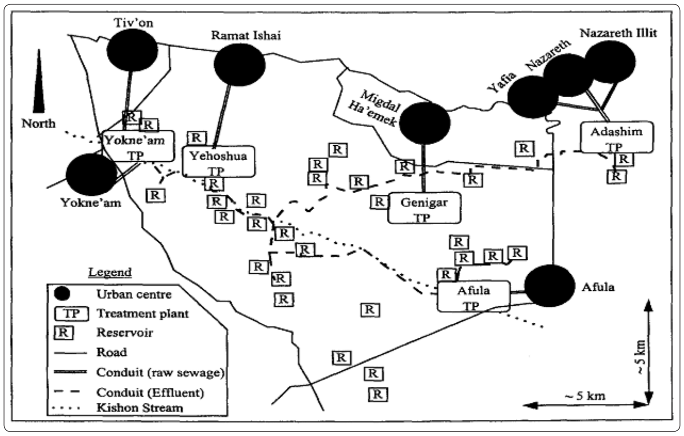

Figure 1: Map of the master plan after Friedler, 1999

The innovative governance is developed during 1989-1992. Technical plans are presented to every urban settlement and agreements about the participation are reached with all of them. Though Afula entered into the agreement a few years later after depreciation of its wastewater treatment plant. All rural settlements agreed on the participation and purchases of effluents. Legal contracts followed. The urban settlements are obliged to establish and operate wastewater treatment in line with the plans specifications, cover costs of some pipes, and pay fees for operations and maintenance based on the contracts. The rural settlements are obliged to pay fees for the effluents allocated to them based on the plans. The Palgey Ma'im is obliged to allocate the effluents to the rural settlements based on plans and operate the whole regional system in compliance with the national regulations. It is sole manager of the network, which includes upgradation plans for new standards and local issues as additional aeration and resolving smells, respectively; Sofer, Personal communication, 27 June 2014) [36].

Benefits

In 2014 more than 250,000 people are served by this regional sanitation system. While 16 million m^3 effluent a year is reused for irrigation, which is 80% of all wastewater because 20% evaporates from the reservoirs, the spillovers into environment are negligible [44]. Palgey Maim delivers cheap services because wastewater treatment plants of several urban settlements are served and their performance is enhanced by biodegradation in the reservoirs to cope with the regulatory standards. For example, the wastewater treatment plant of the town Migdal Ha'emeq with capacity of 10,000 m^3 a day costs USD 0.15 per m^3 whilst a comparable plant by scale in Israel is usually twice costlier (at rate USD 1 = NIS 3.2). Farmers purchased effluents at USD 0.18 per m^3 in 2014 (Sofer, Personal communication, 27 June 2014). It is cheaper than the national water supplier whose prices per m^3 irrigation water were: USD 0.3 for the non-restricted irrigation with effluent, USD 0.43 for saline water and USD 0.70 for potable water [45]. This system generated that year about USD 5 million cost-savings compared to the conventional sanitation with effluent reuse, equivalent of USD 15-20 cost-saving per person in that region, which is about 30% efficiency increase. Table 1 shows the estimates.

Table 1: Benefits of the Palgey Ma'im System Compared the Conventional Sanitation

250,000 people 16 million m^3 effluent, 80% reuse	Urban settlements			Rural settlements		
	Wastewater treatment		Total cost	Effluent purchase		Total cost
Conventional	Water use	Price USD/m^3	USD million	Effluent use	Price USD/m^3	USD million
Palgey Ma'im	16	0.7	-11	13	0.3	-4
Saving	16	0.5	-8	13	0.18	-2
			3			2

In addition to sanitation that complies with the national regulation, several co-benefits are realized. Since the biodegradation in reservoirs is situated in the rural areas no much space for the wastewater treatment plants is used in dense urban areas, which is particularly relevant for the Arab settlements in the Jezreel valley and the reservoirs provide buffers for the industrial discharges (Yaganov, Personal communication, 5 November 2015). An institutional co-benefit is that this system connects all urban settlements, including the economically weak ones (Ben Meir, Personal communication, 21 February 2002), while seven out of eleven settlements are considered weak economies [46]. Furthermore, agreements with the Palgey Ma'im resolved disputes between the urban and rural settlements and the farmers gained autonomy because they are less dependent on the national allocation of water and more resilient to droughts, which allows long-term planning.

This case illustrates that citizens initiatives can create cost-effective public service and generate co-benefits, albeit some imponderable. Although this system is approved by the national authorities and the local authorities participate it is the only case found in Israel because the rigid regulations and organizational challenges impede dissemination (Yaganov, Personal communication, 5 November 2015). Since the available technologies are combined into a cost-effective system this governance can be easier applied in countries that have less rigid regulations and more flexible organizations in sanitation.

Decentralized Systems

A decentralized wastewater treatment with reed, sweet flag, bulrush, willows and other wetland plants is pursued by farmers, social enterprises and non-governmental organization, referred to as constructed wetlands, helophytes filter or biofilter. This technological innovation is shown based on the helophyte filter applied by the Wetlantec, a firm that have treated a few million person equivalents wastewater from households, farms, industries and landfills during last twenty four years.

Constructed Wetlands

Fast growing, perennial plants are used for the constructed wetland as explained in many manuals [47-50]. Although an open source technology experience in constructions is needed. When used for treatment of grey water, waterways and soil the polluted water flows through the helophyte fields horizontally, or it is pumped up on top of the filter and flows vertically. Both methods are cheap but need much space for treatment of grey water. The space use is estimated with the kinetics of BOD removal.

$$A = \frac{Q(lnC_0 - lnC_t)}{K_{BOD_5}} \qquad (1)$$

The helophytes area, A, in m^2 depends on the averages of flow Q in m^3/day and difference between the inlet and outlet, $(C_o - C_i)$ measured in the biodegradation oxygen demand (BOD) during 5 days in mg/l, corrected for reaction parameter per day. This parameter depends on the outdoor temperature. The reaction parameter is estimated empirically based on tests in various climates; for instance, it is 0.067 in cool United Kingdom, 0.083 in Denmark up to 0.17 in warm Bangalore in India [51]. It implies that the biodegradation is twice faster in warm climate. The necessary area varies from 1.0 m^2 to 2.0 m^2 per person equivalent of wastewater for a horizontal flow helophyte filters and from 0.8 m^2 to 1.5 m^2 for the vertical ones; the lower bounds refer to the treatments in warm climates [50]. The black water from households and industrial must be pretreated in digesters or septic tanks sedimentation and anaerobic digestion followed by the vertical flow helophyte filter. Various adaptations aiming to reduce the space use and costs are pursued, such as dispersion of black water in soil without the sedimentation in digester, better spread of wastewater on the filter and aeration of soil for faster biodegradation at the roots. However, even most effective technologies are a few times more space consuming than 0.15 m^2 per person equivalent in the large scale multistage wastewater treatment plants, whilst bio-membranes that combine membranes and biodegradation are even denser but costlier. If space is available the constructed wetlands are cost-effective because plants do much work but scarce spaces in the urban areas impede widespread uses.

This sanitation technology for the black water is explained based on the Wetlantec experience. The scale varies from a few to a few thousand person equivalents per biofilter unit that is usually located nearby the pollution source. After placing digesters in pits construction of the vertical flow helophyte filter starts. The Pictures serial 1 shows main steps in the filter construction at a school with 1000 pupils and 150 households on 400 m^2 in Culemborg, a middle-size town in the Netherlands. From upper left clockwise, the construction steps cover: excavation 1 m deep; then layers of foil, shells, lava and clean sand; followed by drip pipes under the sand; and sowing reed on top of the filter. A qualified constructor is needed because damaged digesters, deficient layers, messy dripping pipes or poor connections undermine the cost-effective operations, cause smell and other kinds of nuisance. Sound constructions can operate continuously during a few decades without major revisions but periodic emptying of the biodigesters, tuning of the pumps and suchlike maintenance. Designs can tune the filter lay-out to the needs and spatial situations in communities.

The operations cover: sedimentation and anaerobic digestions in the biodigester in the 1st stage, then pumping up and spread of wastewater on the filter, trickling down activates the aerobic biodegradation at the plant roots in the 2nd stage along the absorption of nitrates, phosphate and other minerals to seashells and lava while foils protect soil from pollution in the 3rd stage and finally grown reed is mowed as the polishing. Good results are also obtained with willows in the temperate climates, Cyperus and Miscanthidium and other plants in the warm climates [52]. After quality control, effluents can be discharged or reused for toilet flush, gardening and other technical purposes. The system operates during cold weather, even in snow though slower, cause no smell because the biodegradation evolves under surface though protection from hogging and trampling, as well as periodic checks for maintenance of the installations are needed. If land is abundant or cheap, such constructed wetlands can meet high standards at lower costs than the conventional systems because they reduce the length of sewage, plants do most of treatment works, maintenance is low and the energy use is negligible. Hence, most sanitation with the constructed wetlands is found in rural areas and small towns but rarely on edges of cities where the land use is costly.

Figure 1: Construction of a Constructed Wetland

Table 2 shows performance of such biofilter which is certified by the Dutch authority (KIWA). Key performance indicators are presented vertically and the regulatory standards are compared to the certified performance based on a few dozen field tests. This technology performs above the standards if it is well-constructed and decently operated.

Table 2: KIWA Certification of the Wetlantec Vertical Flow Helophytes Filter in mg/l; Highest Possible Certification Criteria (IIIB)

Parameter	Regulation criteria	Certified average
COD	100	17
BOD	20	3
N – Total	30	18.2
NH4-N	2	0.4
P – Total	3	0.09
Total Suspended Solids (TSS)	30	2.2

Benefits

Given that land in the urban settlements is expensive valuable services should compensate much space use by the constructed wetlands for the grey water. A review of 18 studies on such services shows that the constructed wetlands vary by area and co-benefits per hectare. The areas vary from 0.06 ha in Hangzhou Botanical Garden in China to 55 000 ha on the flood plains of Elbe river in Germany, whereas the estimated benefits per hectare vary from USD 1.7 in Vaza Logone in Cameroun to USD 39 140 in Cheimaditida and Zazari lakes in Greece; extremely high benefit in Hangzhou is excluded because based on a small area. Correlations of those benefits with the valuable services across the cases indicate that most beneficial are flood control and buffering of flooding, natural habitat with biodiversity and water reuse whilst less beneficial are protection of the surface water and groundwater, non-consumptive recreation, commercial fishing and hunting. The benefits increase in vicinity to large settlements which supports compensations for the space use if the valuable services are developed. Those constructed wetlands are purposed for waterways and flood protection rather than sanitation of households and industries.

The valuable services of constructed wetlands for sanitation are also assessed. The trailblazing work on black water is done by the Wastewater Gardens, an international network of social enterprises and non-governmental organizations that is established after experiments with artificially closed ecosystems called Biosphere 2 in the United States [53,54]. The treatment mainly used the biodigester with the effluent reuse for gardening at hotels and visitors' centres. Picture serial 2 shows gardens at a hotel in Mexico.

Figure 2: Wastewater Gardens (publications of the Wastewater Gardens Network)

This system adds value but cannot meet all stringent criteria for effluent quality in high income countries unless the biodigester technology is substantially improved or the retention time in digester is longer which needs voluminous digesters, large investments and space use. Table 3 shows the results based on reporting by the Wastewater Gardens [54].

Table 3: Effluent Quality of the Wastewater Gardens

Parameter	In Septic tank mg/l	Effluent mg/l (Dutch norms)	Removal %
BOD	**145**	**17.6 (20)**	**87.9**
Total Phosphorus	**8.05**	**1.9 (3)**	**76.4**
Total Nitrogen	**47.6**	**10.0 (30)**	**79**
Total Suspended Solids (TSS)	**69.9**	**38.9 (30)**	**44.4**
Coliform bacteria	**49×10^6**	**2.2×10^3 (nearly nil)**	**99.8**

More valuable services based on the horizontal and vertical constructed wetlands for the black water are assessed with web search and crowd sourcing [55]. Firstly, the web search reveals few dozen exemplary services at households, tourist centres and institutions mainly in rural areas. The services are effluent reuse for gardening at households and education centres, reviving of ecosystems for leisure, biodiversity and landscaping, cleansing ponds in parks, sites for social gathering and waterways for fishing. Main benefits are water saving, groundwater protection, biodiversity in parks and gardens, nature experience on footpaths and walk trails, wood works of arts, fishing in ponds and rain harvesting. The reuse of water and organic matter in effluents save costs whilst the biofuel production, fees for the biodiversity gardens, recreation, fishing, boating, wood carving, and water storage in dry areas generate income. The cost-benefit assessments are scarce but a few indicate net benefits. Secondly, ideas for the services are generated in a meeting organized by the Enviu, a social enterprise specialized in the crowdsourcing. Twelve experts confirmed the abovementioned services and added facilities for religious and ceremonial sites, sanitation with spots for charging solar power, schooling about natural filtering, hygiene and washing and biofilters for gardening and climate control on the roofs.

Table 4 shows costs and benefits data of the Wetlantec filters, similar to the school in the Netherlands, pilot at a school in Ukraine and a feasibility study in India. The results indicate about 40% savings of fees in the Netherlands, nearly 20% in Ukraine and net benefits can be attained in the India situations without the effluent fees if the biofilter has low unit costs because large scale and large co-benefits of clean water in water scarce areas are generated. The cost-savings in the Netherlands and Ukraine are mainly due to lower fees for sanitation and technical water, the water reuse and biogas are relevant in India. Low-cost digester would make large difference because it needs 30% of investments in an installation in the Netherlands, even 55% in Ukraine and more in India, and its depreciation exceeds 60% of the annual costs. The constructed wetlands are cost-effective, can be even net beneficial, if the constructive failures and corruption are avoided but unfortunately, these deficiencies are experienced.

Table 4: Costs and Benefits of Vertical Flow Constructed Wetlands

All in 1000 USD; p.e. is person equivalents	Netherlands, school (NL)	Ukraine pilot (UA)	India study (IN)
Investments	112	73	182
Capital costs	15	9	24
Operational costs	13	5	12
Total annual costs	28	15	36
Benefits			
Saving fees effluent (1)	26	9	-
Saving charges water (2)	9	5	23
Biogas consumption	3	3	14
Valuable services	1	1	3
Total annual benefits	39	17	40
Net benefit	11	3	4
*UA labor 50% of NL (1) NL 1.1/m^3, UA 0.2/m^3; IN 0 (2) charges: NL 0.4/m^3, UA and IN 0.2/m^3			

Conclusions

A few billion people in the world have no effective sanitation, even in wealthy EU more than 70 million people lack it, though the conventional sanitation with sewage and multistage wastewater treatment effectively prevent water-borne diseases and environmental degradation. High cost is the cause for this deficiency and the cost of sanitation increases because more pollution reduction technologies are added at the end of sewage pipes. Innovative citizens initiatives can resolve this lock-in. A social innovation with use of the conventional technologies and a technological innovation in a conventional organization are presented. Their costs and benefits are estimated with particular attention to valuable services that can generate co-benefits in addition to the benefits of compliance with high standards in sanitation and pollution prevention.

The social innovation elongated the conventional sanitation into a regional system for reuse of effluents on farmland in Israel. It is implemented by a farmers' association that manages this system for the urban and rural settlements in conformity with the national regulatory standards. Effluents of the municipal wastewater treatment plants are distributed through the pipe network with reservoirs for additional biodegradation towards the effluent reuse for irrigation on farms. This farmers' association serves about 250 000 people in the urban areas with the cost-effective wastewater treatment and in rural settlements with cheap effluent supplies because 30% efficiency-increase compared to the conventional sanitation is attained. The technological innovation refers to the decentralized system of digesters and constructed wetland for sanitation for housing, industries and landfills driven by social entrepreneurs and non-governmental organizations. Experiences of a firm that treated a few million person equivalents during last two decades show that such sanitation is cost-effective if constructed and operated well. This service generates co-benefits due to lower effluent fees and water charges, deliveries of energy and amenities in gardening, biodiversity management, leisure and beautification. Beneficial sanitation is generated when cheap technologies and valuable services are attained.

The dissemination of such innovations, however, is slow because the managerial capabilities are scarce, regulations are rigid, and authorities have little interests in cheaper innovations. More cost-effective sanitation is possible due to the citizen's initiatives but policies should facilitate their innovations. Strict standards for effluents with high fees for discharge of wastewater and flexibility with respect to the technical and organizational means foster the innovative citizens' initiatives.

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