Sludge dewatering using the reed bed system in the Gaza Strip, Palestine

Abdel Majid Nassar[1], Michael Smith MCIWEM[2] & Samir Afifi[3]

[1]Civil Engineering Department, Islamic University Gaza, The Gaza Strip, Gaza, The Palestinian Territories; [2]WEDC, Loughborough University, Loughborough, UK; and [3]Environmental & Earth Science Department, Islamic University Gaza, The Gaza Strip, Gaza, The Palestinian Territories

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Correspondence
Michael Smith, WEDC, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK. Email: m.d.smith@lboro.ac.uk

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Abstract

Sludge treatment using reed beds is more attractive in the Gaza Strip than traditional sludge drying beds. Sludges having solids contents of 1–2% can be applied to reed beds at a loading of 40 cm/m^2 every 2 weeks. The infiltration rate for a reed bed system is high, and the evapotranspiration rate is typically 170% of pan evaporation. The cost of sludge treatment using reed beds is 0.34 US$/m^3 compared with 1.01 US$/m^3 for treatment using conventional drying beds. This paper presents the results of using reed beds for sludge treatment in the Gaza Strip for 3 years.

Introduction

The Gaza Strip is a densely populated area. More than 1 200 000 inhabitants live in an area of only 365 km^2. The environmental situation has deteriorated owing to the difficulties and constraints associated with the ongoing political situation in the region. Three wastewater treatment plants have been constructed in the area to serve the population. Stabilization ponds and aerated lagoons are the current wastewater treatment systems. The existing plants are overloaded and poorly managed, with the result that the effluent quality is slightly better than that of the influent. Sludge does not generally receive any treatment other than being removed from ponds and then spread on the ground in open areas around the treatment plants, creating a serious environmental health risk. Recently, sand drying beds were constructed at one treatment plant for sludge dewatering. The system failed to solve the problem of sludge dewatering and stabilization, as the beds did not perform well. The construction of three new treatment plants is now being planned to serve the whole population of the Gaza Strip. Activated sludge and extended aeration are the proposed systems for the new treatment plants. It is estimated that by 2025, more than 11 000 m^3 of sludge will be generated daily in the Gaza Strip, with a suspended solids (SS) concentration of approximately 1%. Sophisticated systems for sludge treatment in the area are not feasible. The ability of residents to pay is limited, and the human skills needed to deal with high technology are not available. Land filling is not recommended as land is scarce within the Gaza Strip, and no more land is available for disposal of sludge to landfill. Low-cost systems, such as reed beds, could be a solution to the sludge disposal problem.

'It is not easy to find a solution, which allows good management of sludge at reasonable cost' (Liénard *et al.* 1990). A reed bed system for sludge dewatering is an innovative process (Fox Engineering 2003), being a combination of a traditional sludge drying bed and natural wetland (Burgoon *et al.* 1997). Reed beds are widely used for sludge treatment throughout Europe, Asia and Australia, and in more than 50 locations in the United States. Reed bed technology features low construction costs and minimal day-to-day operation and maintenance costs (Keefer 2000). The system reduces the water content of sludges, minimizes the quantity of solids, and provides sufficient storage time for stabilization of bio-solids before disposal.

Reeds act in many ways to alter the character of solids and metals present in the sludge. Firstly, their root system encourages oxygen to enter the sludge around the roots, which boosts the population and activity of naturally occurring microorganisms, which in turn mineralize the sludge (Roy Consultants Group 2003). Secondly, the plants grow rapidly in this nutrient-rich medium and absorb some of the minerals, in addition to drawing water from the sludge (Roy Consultants Group 2003). Thirdly, roots extend from the reed stems into the bio-solids,

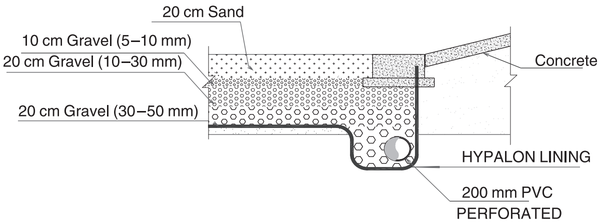

Fig. 1. Schematic diagram of reed bed cross section.

creating a system of channels in the bio-solids, encouraging continuous drainage and preventing the formation of a semi-impervious bio-solids layer, which is typical in unplanted beds (Hellstrom & Jager 1994). Meanwhile, the processes of evaporation, drainage and plant uptake combine to transform the sludge into a stable humus-like fertilizer material, which can be used either to seal sanitary landfill cells or as a soil conditioner. Although there has been much research into the performance of reed bed systems, there is still need for further investigation into the design and performance of reed bed systems in specific locations.

This paper presents the results of a reed bed system constructed in the Gaza Strip and monitored for 3 years.

Materials and methods

Pilot project description

The pilot system consists of two beds, each having a base area, in plan, of 200 m^2, and with concrete banks sloping at 1 : 3. One bed was planted with the reed *Phragmites australis* and the other was left unplanted. The beds were constructed on the same site as the Gaza City wastewater treatment plant. This location was selected because of the availability of land and the possibility of using sludge from the treatment plant. The beds were open (uncovered), and each bed was provided with a drainage system at the base, consisting of perforated unplasticized polyvinyl chloride pipes of 200 mm diameter surrounded by gravel 5–7 cm in size. The bed media consisted of three layers of aggregate. The bottom layer was 20 cm deep, with stones of 3–5 cm diameter. The second layer was 20 cm deep, with stones of 1–3 cm diameter. The third (top) layer was 10 cm deep, with stones of <1 cm diameter. On the top of the three layers, a 20 cm deep layer of sand was laid to a slope of 1 : 50. The bottom of each bed was sealed with a 'Hypalon' lining. Hypalon is an impermeable geotextile, which is used to prevent water from percolating through the base of the bed. Figure 1 shows a section through the bed base and the edge of a bed showing the configuration of drainage and gravel layers. The influent system was a 200 mm diameter pressure pipe provided with a current meter, so that flows to the drying beds could be measured. The pressure pipe distributed sludge to the two beds through inlet pipes fitted with valves. Beds were loaded with sludge frequently by controlling the valves installed at the inlet pipe to each bed. The outflow from the drainage system led to a collection chamber where the leachate was collected by gravity and then pumped back to the treatment plant for further treatment. The outlet was provided with a water meter to measure the quantity of infiltrated water draining from the beds.

Operation

Hydraulic loading measurement

During each sludge application, the quantity of loaded sludge was measured using the current meter installed at the inlet as described above. The reading on the effluent meter measuring the flow of infiltrated water was recorded at the beginning and at the end of each loading application. From the meters at the inlet and outlet, the quantities of sludge applied and water draining from the beds were calculated.

The hydraulic load applied was calculated as cm/m^2 day according to the following formula:

$$\mathrm{HLR} = \frac{Q_\mathrm{d} \times 100}{A_\mathrm{s}} + P,$$

where HLR is the hydraulic loading rate (cm/m^2 day), Q_d is the hydraulic load (m^3/day), A_s is the plan surface area of accumulated sludge on the drying bed (m^2) and P is the rainwater precipitation (cm/day).

The slopes of the surface and banks of the drying beds were taken into consideration by calculating the HLR. The HLR was calculated based on the basis of the surface area of sludge, which increased as the depth of accumulated sludge increased. For the first 3 months, sludge was applied twice a week, after which it was applied once a week for another 3 months. It was noticed that in summertime (from May to September), the drying beds could be loaded each week, based on the quantity of applied sludge. Applying the same amount of sludge to both beds at the same time was favourable for the study and for comparison of the performance of planted and unplanted beds at the same loading rate. The site of the pilot project is close to the Israeli 'Nitzarim settlement', and security restrictions prevented travel to the pilot project at certain times. At some times of the year, loading of one or both beds was therefore not possible. From our experience of monitoring the beds, it was better to apply sludge every 2 weeks, with double the amount applied every week for planted and unplanted beds. The performance and health of the reeds were better, and less sludge accumulated in the bed. However, hydraulic loads applied to the two beds were not the same for the whole period of the project, and loading was sometimes halted. On some occasions (in summertime), the planted bed was loaded with more sludge than the unplanted bed to investigate the potential hydraulic loading capacity of the planted bed.

Measurement of 24 h infiltration rate

Drainage flows were measured for the first 24 h after loading for both planted and unplanted beds. From the quantity infiltrated during the first 24 h, the initial infiltration rate can be determined. This test was carried out once or twice each month. A 24 h infiltration rate was calculated using the following formula:

$$I_r = \frac{Q_d \times 1000}{A},$$

where I_r is the infiltration rate (mm/day), Q_d is the quantity of drained water in the first 24 h (m^3) and A is the plan surface area of accumulated sludge on the drying bed (m^2).

Calculation of solids loading rate

Solids loading rates are calculated based on the basis of HLR and the solid per cent of the applied raw sludge. From the concentration of SS and the hydraulic loading, the solids loading rate is determined according to the following formula:

$$\mathrm{SLR} = \frac{SS \times Q_m}{A_s \times 1000},$$

where SLR is the surface loading rate (kg/m^2 month), SS is the suspended solid concentration in raw sludge (g/m^3), Q_m is the hydraulic load (m^3/month) and A_s is the plan surface area of accumulated sludge on the drying bed (m^2).

Estimation of evaporation and evapotranspiration rates

Evaporation and evapotranspiration rates were estimated by measuring all flows, both of sludge applied to the beds and of filtrate water draining from the beds to be pumped back to the treatment plant.

The evaporation rate (E_p) or evapotranspiration (E_t) rate per month is calculated based on the following formula:

$$E = \frac{(Q_m - Q_d) \times 1000}{A_s} + P,$$

where E is the evaporation or evapotranspiration rate (mm/month), Q_m is the hydraulic load (m^3/month), Q_d is the drained water (m^3/month), A_s is the plan surface area of accumulated sludge on the drying bed (m^2) and P is the rainwater precipitation (mm/month).

The above equation excludes water stored in the beds.

Results and discussion

Hydraulic loading and dewatering

Figure 2 shows the HLRs for both beds during the operational period. Whatever the applied quantity of sludge, 4–5 days later infiltration stopped in the planted bed, whereas it took more than 7 days for infiltration to stop in the unplanted bed. After infiltration from a bed stopped, cracks began to develop on the upper surface of the sludge. This was more noticeable on the planted bed. The most suitable time to apply more sludge was when the cracks were 10 cm deep, which occurred on average 10 days after infiltration stopped. The rate at which cracks developed was more rapid in summer than in winter. In summer, 10 cm cracks developed on the accumulated sludge surface 5–7 days after infiltration stopped. It was also noticed that cracks did not occur at the same rate in all parts of a bed. Cracks developed more quickly where drainage was good, close to the area where drainage pipes were installed. This could be due to variations in ventilation. The outlet of the perforated pipe was open to the atmosphere; this increased ventilation and appeared to make the reed performance more effective. It was evident that the reeds in this area were more dense and green, although the accumulated sludge depth was greatest here.

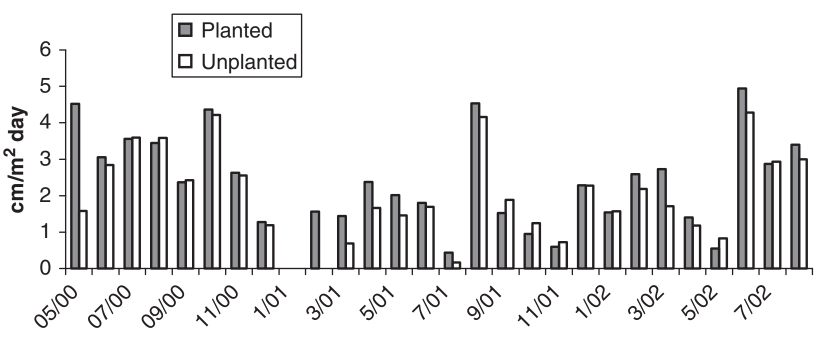

Fig. 2. Applied hydraulic load.

Owing to the bed slope, the depth of accumulated sludge on the side nearest the outlet pipe was more than that on the other side of the bed by approximately 20 cm.

It was noticed that keeping the beds saturated had a negative impact on the development of the reed plants. This was noticed in Wadi Gaza, which was the source of reeds. Reeds in Wadi Gaza are saturated for most of the year, but the health of the plants in the reed bed was better than that in the Wadi. Reeds in the Wadi remain dry for part of the year (during the summer) when there is no rainwater and the existing water is saline and stagnant. Reeds in the planted bed were taller, thicker and greener than those in the Wadi. The better health of reeds in the bed could be due to:

- Frequent loading of the bed, which provides the reeds with better conditions. Most plants survive better when irrigated at intervals, not continuously.
- Sludge contains more nutrients, and is more suitable for plant growth, than the saline water in the Wadi.
- Dryness of the bed surface and development of cracks facilitate oxygen transfer to the plant roots, which is necessary for keeping reeds in good health.

Table 1 presents the HLR in the different operational stages of the two beds. Hydraulic loading was started in May 2000, and continued until August 2002, when the accumulated sludge drying period was started for 4 months. The hydraulic loading period for this study was divided into four intervals, and HLRs were studied during each interval.

The first interval was from planting time (May 2000) to December 2000, when the reeds were nearly fully grown. The second interval was from January 2001 to the end of May 2001. The third interval was during the second half of 2001 (from June to December 2001). The fourth interval included the rest of the project period (January 2002 until the end of August 2002).

With reference to Table 1, the following points should be noted:

1. The loading rate in the first interval was high; this was due to loading two times per week.

2. During the second interval, the loading rate was low. This was due to periods when security conditions prevented access to the pilot plant, and loading was not possible, mainly for the unplanted bed.

Table 1 Hydraulic loading rate (cm/m^2 day) in the different operational stages

Period	Date	Planted	Unplanted
First interval	May/Dec. 2000	3.2	2.7
Second interval	Jan./May 2001	1.8	1.4
Third interval	June/Dec. 2001	1.7	1.7
Fourth interval	Jan./Aug. 2002	3.0	2.6

3. Loading rate during the fourth interval was high, especially in the planted bed. The loading rates show high performance in the third year (fourth interval).

4. For 3 years, the planted bed was loaded with a sludge loading rate of 2.9 cm/m^2 day on average, and the unplanted bed was loaded with an average loading rate of 2.6 cm/m^2 day, excluding the times of irregular sludge loading. Such figures represent the applied rates, not the potential capacity of the beds. It was noticed that beds, in particular the planted bed, could be loaded at higher rates.

Infiltration rate in 24 h

In general, studying the infiltration rate of the system is difficult as infiltration rates vary from day to day following sludge loading, and infiltration stops a few days after loading. It is clear that infiltration rates are influenced by hydraulic load, solids load and time. It is difficult to study the impact of each of these three factors independently, as all three variables are constantly changing. It was noticed, however, that the solids content of the sludge was almost constant, especially after the first 6 months of the project. It was therefore decided that as the solids content was almost constant, hydraulic load and solids load were directly proportional to each other and could be represented by hydraulic load as a single variable.

The study period was divided into three separate 'years' (part or all of calendar years) to facilitate a study of the relationship between infiltration rate and both time and hydraulic load.

Year 1 is the period from starting the project in May 2000 until the end of 2000, covering the first interval as shown in Table 1.

Year 2 is 2001, from January until December, covering the second and third intervals as shown in Table 1.

Year 3 is 2002, from January until August, covering the fourth interval as shown in Table 1.

Figure 3 presents the 24 h infiltration rate for the 3 'years' of the project. On the basis of the results shown in the figure, the following points can be noted.

The infiltration rate in summer was higher than that in winter. In the planted bed, the infiltration rate increased from 60 mm/day in winter to 200 mm/day in summer. This compared with an increase from 60 mm/day in winter to 150 mm/day in summer in the unplanted bed. This was because temperatures are higher in summer, reeds are more active, and evaporation/evapotranspiration rates are higher. All these tend to increase the rate at which the accumulated sludge dries out. The applied hydraulic load in summer was higher than that in winter, which increased the infiltration rate.

The infiltration rate in the planted bed was greater in year 3 than in year 2, especially in summer. Using infiltration rate as an indicator of bed performance shows that the bed performance improved with time.

It was noticed that the 24 h infiltration rate in the planted bed was higher than that in the unplanted bed in summer, whereas in winter it was approximately the same.

HLR and 24 h infiltration rate

To study the relationship between hydraulic load and infiltration rate, the authors analyzed the results for the 3 years. Figures 4 and 5 show the relationships for the planted and the unplanted beds. The results obtained seemed scattered, and the relationships between HLR and infiltration rate were not very clear. Drawing a trend line for the results and taking the correlation coefficient (R^2 value) as an indicator for such a relationship made the relationships clearer. In general, the trend line suggested that the infiltration rate was directly proportional to the HLR. The strength of this directly proportional relationship was more evident in the planted bed than in the unplanted bed. The correlation coefficient was a good indicator of the strength of the relationship. R^2 for the planted bed was 0.45, whereas it was only 0.0145 for the unplanted bed. This means that hydraulic load significantly affects infiltration rate in the planted bed, whereas there is less evidence of such a link in the unplanted bed.

In general, a third of the sludge applied could infiltrate within 24 h when a hydraulic load of 1.1 m^3/m^2 was applied every 2 weeks in summertime to the planted bed. On average, 25% of the applied hydraulic load infiltrates within 24 h in the planted bed, compared with only 20% in the unplanted bed. The infiltration rate in the planted

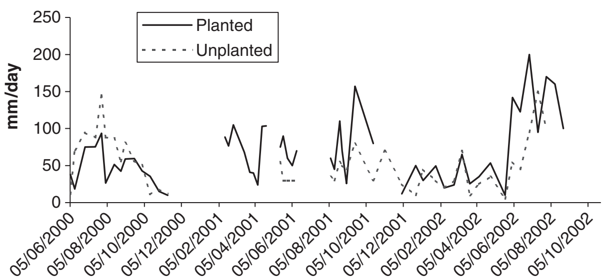

Fig. 3. Twenty-four hour infiltration rate (mm/day).

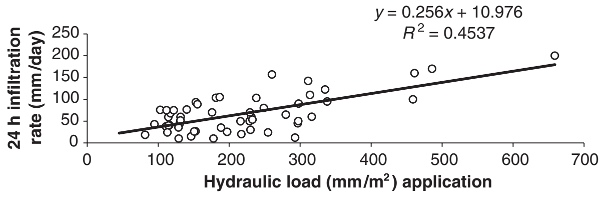

Fig. 4. Twenty-four hour infiltration rate versus hydraulic load (planted bed).

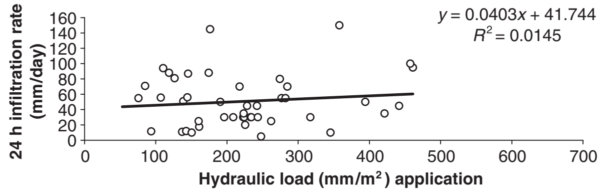

Fig. 5. Twenty-four hour infiltration rate versus hydraulic load (unplanted bed).

bed increases with time, but any increase in infiltration rate with time in the unplanted bed is less evident.

Solids loading rate capacity

The solids loading rate was increased from 3.8 kg/m^2 month for the first 6 months up to 11.3 kg/m^2 month in the third year in the planted bed (see Fig. 6). In the unplanted bed, the solids load was increased from 3.3 to 9.9 kg/m^2 month for the same time period. In the second year (2001), lower solids loadings were applied. This was due to access restrictions preventing application of sludge to beds for long periods between January and March and between June and August. During these periods, it was very difficult to reach the site, because of the dangerous security situation. On average, for the whole period of the project (excluding irregular loading periods), 7.5 kg/m^2 month of solids were loaded on the planted bed whereas 6.7 kg/m^2 month were loaded on the unplanted bed.

Evaporation and evapotranspiration

The depth of sludge in the drying beds increased by less than 15 mm/month. This means that the increase of water stored within a bed was less than 10 mm/month (assuming that the moisture content of accumulated sludge is 70%). As the average evaporation/evapotranspiration was consistently more than 200 mm/month for the planted bed, and approximately 200 mm/month for the unplanted bed (as shown in Fig. 7), this means that the quantity of stored water was not a significant amount ($\approx$ 5%) compared with the volume of water lost through evaporation or evapotranspiration. For this reason, the volume of water stored in the bed was assumed to remain constant.

The evaporation rate from the unplanted bed was compared with the evapotranspiration rate from the planted bed, and both were compared with the pan evaporation rate measured at the Gaza meteorological station.

To study evaporation/evapotranspiration rates, the project period was divided into four intervals; the average evaporation/evapotranspiration rate was calculated for each interval and compared with pan evaporation rates. The division of the study period into four intervals was

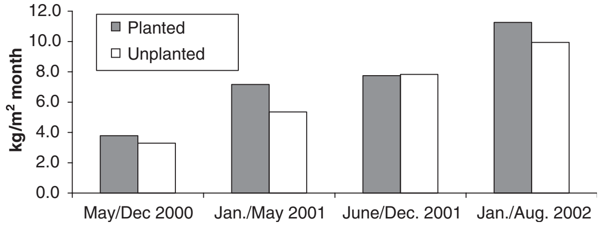

Fig. 6. Average solid loading rate.

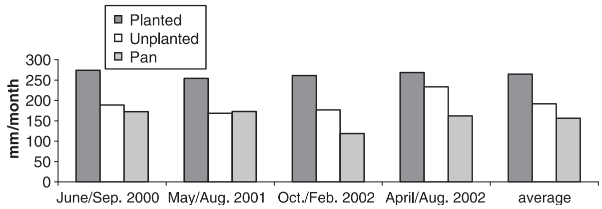

Fig. 7. Evaporation and evapotranspiration.

based on summer/winter periods, as seasonal weather conditions are expected to be the most important factor affecting evaporation/evapotranspiration. Evapotranspiration rates from different crops can be estimated by applying factors to the pan evaporation rate, and evapotranspiration depends on the climate (radiation, temperature, humidity, wind speed, etc.), crop factors, management practices and environmental conditions (Allen *et al*. 1998).

Figure 7 shows the results from the four periods considered. Three of these (June–September 2000, May–August 2001 and April–August 2002) can be considered as summer (dry) periods, and one period (from October 2001 to February 2002) can be considered as a winter (cooler with some rain) period. From Fig. 7, the following points can be noted.

Pan evaporation was lower during the period from October 2001 to February 2002, consistent with the cooler winter climate conditions.

Evapotranspiration rates for the planted bed range from 254 to 274 mm/month, which is nearly constant for all periods during the study period. The calculated values for evapotranspiration represent the actual evapotranspiration and not the potential evapotranspiration from plants. In summer, the bed is only saturated for between 4 and 5 days after each loading, although evapotranspiration calculations were carried out for the whole period (14 days) between sludge applications. In wintertime, the beds remain saturated for longer periods owing to a decrease in the infiltration rate and the addition of rainwater. It is assumed that evapotranspiration during the summer periods was limited by the amount of water available, and that drying of the beds in summer periods reduced the actual evapotranspiration to less than the potential, whereas in winter the beds remained saturated and evapotranspiration could occur without constraint at the potential winter rate.

The evapotranspiration rate in the unplanted bed varied from 168 mm/month in winter months to 233 mm/month in the summer. Evapotranspiration from this bed was comparable to pan evaporation during June–September 2000 and May–August 2001, but greater than pan evaporation during October 2001–February 2002 and April–August 2002. Evapotranspiration is a complex process, and the explanation for this finding is beyond the scope of this study.

On average, evapotranspiration from the planted bed is 170% of pan evaporation. Allen *et al*. (1998) suggest that for a reed swamp in a temperate climate, evapotranspiration is likely to be between 1.0 and 1.2 times the pan evaporation. Gaza is in an arid tropical climate, where evapotranspiration from reeds is expected to be greater than that in a temperate climate for the following reasons:

- Most plants can exert osmotic pressures up to about 16 atm, whereas reeds can exert osmotic pressures of 20 atm. This enables reeds to absorb more water than other plants, even under adverse conditions, and according to Liénard *et al*. (1995) the evapotranspiration rate from reeds is double the evaporation rate from an open water surface.
- Comparing pan evaporation with evapotranspiration from reeds, Burgoon *et al*. (1997) stated that the evapotranspiration rate for reeds was 6.4 mm/day, whereas the corresponding evaporation rate from open water surfaces under the same climatic conditions was 3.8 mm/day.

It was noticed that the evapotranspiration rate from the unplanted bed was approximately 120% of pan evaporation. Two possible reasons may explain this:

- The surface of the bed is black because of the sludge accumulation. This gives the surface a higher ability to absorb radiant heat from sunshine and increase the capacity for evaporation.
- The sludge surface is not regular, and has greater roughness than a saturated surface. This increases the surface area for evaporation, because the actual surface area is greater than the plan area.

It is evident that reeds have a high evapotranspiration rate, which increases the rate at which accumulated sludge dries out. As the hydraulic loading interval is affected by the rate at which sludge dries out, it means that the evapotranspiration capacity of reeds could increase the hydraulic load applied to a reed bed.

Cost analyses

Existing sludge drying beds (conventional system) at the Gaza treatment plant are operated by loading sludge once every 20–30 days. The total volume of sludge applied at one time is 350 m^3, to a bed of 430 m^2 surface area

(3.2 cm/m^2 day). This is due to evacuation of sludge every 25 days, and not every 3 years as in the experiment. After drying, sludge from the existing system is removed using a 'Bobcat' and transported in vehicles to a solid waste dumpsite. The sludge accumulated in the unplanted bed, owing to its quality, cannot be used in agriculture without additional treatment, and disposal to landfill is difficult because of its high water content. Gaza municipality can easily change from using the current conventional drying beds to planted beds. Table 3 provides a cost comparison for a reed bed system and conventional sludge drying beds (existing) to show the relative costs for the existing system and that proposed (reed bed). The cost analysis is based on a reed bed cycle of 3 years (the feasible duration for accumulation of sludge up to 60 cm depth, which is the recommended depth to desludge the reed bed). Of this, 30 months is for loading the reed bed and 6 months for sludge drying, harvesting and removal. For the existing sludge drying bed, an average 25-day cycle is assumed for loading, drying and sludge removal, based on current operating experience.

Calculations are based on a sludge production of 400 m^3/day to estimate unit capital and running costs for both systems. Cost assumptions are presented in Table 2.

Cost analyses are presented in Table 3 for reed bed and drying bed systems. The analysis includes consideration of the possibility of using sludge from reed beds as a soil fertilizer. From interviews with local farmers, it is assumed that farmers are willing to pay 10 US\$/m^3 for treated sludge, compared with the current price of 14 US\$/m^3 for organic fertilizers. If sludge from reed beds is given free to farmers, the total cost for treating sludge using reed beds will increase from 0.33 to 0.6 US\$/m^3, which is still only 70% of the total cost of using conventional drying bed systems.

Table 2 Cost assumptions

Construction cost of beds (US\$/m^2)	100
Cost of land rent (US\$/m^2 year)	0.2
Project life time (years)	25
Labour cost (US\$/month)	400
Bobcat (US\$/m^3)	1.5
Transportation cost to land fill (US\$/m^3)	2
Landfill charge (US\$/m^3)	3
Reed harvest cost (US\$/m^3)	1.5
Pricing of sludge to farmers (US\$/m^3) dry sludge	10

Table 3 Cost comparison

Cost	Reed bed system	Drying bed system
1. Capital cost		
Hydraulic loading rate (cm/m^2 day)	2.9	3.2
Area required for construction (dunums)	13 793	12 500
Area for paths and roads (15% of construction area)	2069	1875
Total area (dunums)	15 862	14 375
Construction cost (US\$)	1 379 310	1 250 000
Rent cost per year (US\$)	3172	2875
Construction cost per year (US\$)	55 172	50 000
Total cost per year for construction and land rental (US\$)	58 345	52 875
Unit cost (US\$/m^3)	*0.40*	*0.36*
2. Operational cost		
It is assumed that sludge is removed from a reed bed system once every 3 years, with an overall reduction of 98% of total volume, whereas drying beds are evacuated every 25 days with an overall reduction in volume of 90%. Costs are calculated for 400 m^3/day	12	60
Transportation to landfill (US\$)		80
Landfill charge (US\$)		120
Reed harvest cost (US\$)	23.82	
Profit (US\$)	– 60.00	
Total unit operation (US\$/m^3)	*– 0.06*	*0.65*
Total cost (US\$/m^3)	**0.33**	**1.01**

Notes: Profit is shown as a negative value, because it is treated as a negative cost.
1 dunum = 1000 m^2.
The hydraulic loading rate of 2.9 cm/m^2 day for the reed bed system is based on removal of sludge every 3 years.
The hydraulic loading rate of 3.2 cm/m^2 day for the drying bed system is based on removal of sludge every 25 days.

Conclusions

(1) Within the Gaza Strip, a reed bed system for sludge dewatering is more efficient than conventional drying beds. The hydraulic loads, solid loads and infiltration rates are higher for beds planted with reeds than for unplanted beds.
(2) The efficiency of a reed bed system improves with time as greater hydraulic loads can be applied with time.
(3) It was found that hydraulic loading every 2 weeks was preferable to continuous or weekly loading.
(4) It is evident that reeds have a high evapotranspiration rate, which increases the rate at which accumulated sludge dries out. As the hydraulic loading interval affects the rate at which sludge dries, HLRs can be adjusted to maximize evapotranspiration from a reed bed.

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