VATTEN 65:101–109. Lund 2009

A FEASIBILITY STUDY ON SUSTAINABLE WASTEWATER TREATMENT USING CONSTRUCTED WETLANDS – an example from Cochabamba, Bolivia

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Abstract

The city Cochabamba in Bolivia faces increasing environmental problems and health risks due to insufficient wastewater treatment in peri-urban areas. This study evaluates the treatment efficiency of a horizontal subsurface flow (HSF) constructed wetland, built by the foundation AGUATUYA, and investigates the applicability of the method in Cochabamba. The wetland reduces BOD_5 by 80–97 %, COD by 80–90 % and turbidity by 50–80 %. It is largely anaerobic causing low nitrogen removal. Faecal coliform bacteria are reduced by 90 % but the effluent does not meet treatment requirements. The wetland has two sections containing gravel and plastic media respectively. The plastic medium has significantly higher surface area per bed volume but analyses showed little difference in treatment efficiency. To investigate the difference, the wetland outlet has to be redesigned. Tracer experiments showed a large variation in transport time for the gravel section but could not be determined for the plastic section. Nominal retention time was 6.2 and 8 days for the gravel and the plastic section respectively. Reuse of treated wastewater reduces consumption of potable water and energy. HSF wetlands require little energy, construction material and maintenance. They are a good alternative in low-income areas like peri-urban Cochabamba.

Key words – Cochabamba; Bolivia; constructed wetland; horizontal subsurface flow; wastewater; sewage water; water treatment; reuse of wastewater; minor field study

1. Introduction

Solving problems regarding water and sanitation throughout the world is a big challenge. Forty two percent of the world's population lack access to basic sanitation (WHO/UNICEF 2005). Reducing this proportion will help save lives and encourage economic and social development. Untreated infiltration and outflow of wastewater into the groundwater, rivers, lakes and the sea creates massive environmental problems besides being a nuisance and a health risk.

Conventional sanitation and water treatment approaches, largely developed in richer, developed countries, have some requirements difficult for many developing countries and poor areas to meet. Some of these are high capital costs to install pipe networks and treatment plants, high operating and maintenance costs for both plants and networks and finally indoor functional water and sewer connections. (Ujang and Henze 2006)

Cochabamba city is the third largest city in Bolivia and has a rapidly growing population, especially in the peri-urban areas. The urbanisation process has led to an explosion in demand for water and sanitation services. In this study, Cochabamba will serve as an example of a developing country city that faces increasing environmental problems and health risks due to insufficient sewage system coverage and municipal wastewater treatment. The need is great for solutions that are affordable, reliable and sustainable. Ujang and Henze (2006) also define the latter as systems which are technically manageable, socio-politically appropriate and that utilise small amounts of energy and resources, recovering as much usable matters as possible. Three major parts of such a system is source separation of pollutants, decentralisation and reuse of products, in this case e.g. treated wastewater.

The foundation AGUATUYA ("Your Water") in Cochabamba works with design, construction and financing of potable water systems. AGUATUYA implements models which generate local solutions aimed to be appropriate, decent and sustainable. The working models include participation of the clients, for example quarters of the town, villages, municipalities or water cooperatives. In their work with water distribution AGUATUYA has noticed the demand of low-cost sanitation solutions in peri-urban areas and has created pilot projects promoting "Ecological Sanitation" (urin-diverting dry toilets).

In the field of sanitation, the foundation has also constructed a wastewater treatment plant, called PTAR1, as a pilot project to treat wastewater coming from a school in San Antonio de Buena Vista, a peri-urban area in the south part of Cochabamba. Treatment in constructed wetlands is a relatively new solution in Bolivia and is currently tried out at different locations in peri-urban regions (Bomblat 2008, Heredia 2008). This type of treatment solution is very low cost and needs little maintenance, making it suitable for the poorer southern areas in Cochabamba where sanitation so far has been non-existent in many cases (Bomblat 2008). AGUATUYA has run the plant for less than one year and started to monitor the chemical characteristics of the water in June 2008. Further evaluation and testing are still needed. The future goal is to construct large wetlands, treating wastewater from up to 300 households in peri-urban residential areas. The wastewater treatment plant is designed as a horizontal subsurface flow wetland, made especially accessible for evaluation and sampling with several observation pipes. It is also designed to compare two carrier materials: stones and cut pieces of plastic pipes. More understanding of this type of wetland is needed. The aim with this project is to evaluate the treatment efficiency of the constructed wetland PTAR1 and to investigate whether it is worth investing in more constructions of the same type in the Cochabamba region.

2. Constructed wetlands

Constructed wetlands means wastewater treatment systems consisting of one or more shallow basins, where natural processes help to increase the quality of the water. There are three base types of wetlands: free water surface, horizontal subsurface flow and vertical subsurface flow wetlands. They all have macrophyte coverage of varying degree and the flow is usually driven by gravity. In constructed wetlands pollutants are removed through a combination of physical, chemical and biological processes, including sedimentation, precipitation, adsorption to soil particles, assimilation by plant tissue and microbial transformations. (Brix 1993, Kadlec 2009)

In a constructed wetland with horizontal subsurface flow (HSF) the water flows horizontally through a bed of a relatively homogenous medium, like gravel, sand or stones of different sizes. The typical water depth is 50 cm and the water fraction 40 % (Kadlec 2009). The medium in the wetland is underlain with an impermeable layer, made of plastic or soil with very low permeability, to prevent seepage of wastewater down to the groundwater. During the passage through the wetland, the decomposable parts of the wastewater are transformed by microorganisms which are attached as biofilm to plant roots and the filter medium (Thiel-Nielsen 2005). The vegetation in the wetland consists of emergent macrophytes. Gravel, rhizome, roots and dead plant material together create large surfaces for microorganisms to grow on. Biofilm formation on the medium is favoured by the constant addition of nutrients and carbon sources from the wastewater. It also depends on the surface characteristics of the medium. Coarser, more porous media have a larger surface for the microorganisms to grow on. Unlike the free water surface wetland, water should never reach the surface of the HSF wetland. This would mean short circuiting of the treatment, as the water is no longer in contact with the biofilm or the root zone. Hence before entering an HSF wetland, wastewater needs to be pre-treated in a septic tank or similar, to remove solids. If allowed to enter the wetland, these could effectively clog the medium and prevent water passage and subsequent treatment.

3. Nominal retention time

Nominal retention time is a measure of how long time it takes for the whole water volume of a lake, dam or wetland to be replaced. Steady-state conditions and no mixing of the water column are assumed. When calculating the nominal retention time of the constructed wetland porosity is taken into consideration but not plant roots, biofilm nor non-degradable residues. Over longer time, the accumulation of non-degradable residues in the pore spaces and the spreading of plant roots will also add resistance to the flow. The required energy to overcome the resistance of the medium, plant roots and residues, is provided by the difference in hydraulic head between the inlet and the outlet of the wetland. The time it takes for the water to pass from the inlet to the outlet of the wetland may be less than the nominal retention time since the velocity of the water may be higher in certain channels of the bed and shortcuts can be formed. According to USEPA (2000) the actual retention time has frequently been reported to be 40–80 % less than the theoretical retention time. The explanations have been loss of pore volume, preferential flow and dead volume.

4. The pilot plant

The area of the constructed wetland PTAR 1 is 17 m^2 and it is designed for a water depth of 0.8 m. A plastic membrane made of high density polyethylene prevents seepage from the treatment plant to the soil and ground water. The wetland has an inclination of 2 %. The water entering the constructed wetland comes from the kitchen, toilets, hand washing, showers etc. in a kindergarten. Before entering the plant, the water is pre-treated in a grease trap and a septic tank.

PTAR1 is divided into two parts along the flow direction; one part contains plastic medium and the other part small stones (see figure 1). The two sections are in turn divided into 5 chambers, each 1 m long and 1.25 m wide. The stone medium is relatively well sorted with a mean stone diameter of approximately 30 mm. The plastic medium is very well sorted originating from plastic tubes with the outer diameter 32 mm. During the construction of the wetland the tubes were deformed, in order to increase the surface area per bed volume, and cut into ca 30 mm long pieces. In the entrance and the exit of the plant there are 1 m long compartments with larger stones. In the 14 chambers there is a perforated observation pipe close to the outlet of each chamber. The series of 7 chambers is connected through pipes situated at different positions, with variation both horizontally and vertically, in order to maximize the distance the water has to travel through the bed.

Figure 1. *The HSF constructed wetland PTAR1. The black part is the plastic medium and the white tubes are observation pipes.*

5. Methods

Measurements, water sampling, visits, interviews and laboratory analyses were performed in Cochabamba. Water quality analyses focused on nutrients, organic material, bacteria and solids. When determining wetland retention times, evaporation and precipitation were not taken into consideration.

5.1. Flow measurements and calculations

The amount of water pumped out from the effluent tank is measured by a water meter, and the effluent volumes have been registered regularly by AGUATUYA since July 2008. The mean flow between each reading, and an overall mean value, was calculated. The nominal retention time was then calculated using equation 1.

$$RT = \frac{A \cdot y \cdot n}{Q} \qquad (1)$$

where

A = surface area of the wetland (m^2)
y = depth of water-filled part of the wetland (m)
n = porosity, % expressed as decimal
Q = average flow through the bed (m^3/day)

The total flow is divided in half, since half of the flow is assumed to pass into each part (stone and plastic respectively).

A tracer experiment with salt was conducted. Addition of salt to the septic tank should give an increase in conductivity that can be measured to determine flow rate and dispersion patterns. Two kg of salt (sodium chloride with iodine and fluorine) was dissolved in 15 litres of water. The solution was poured into the second chamber of the septic tank. The volume of the septic tank is 2.4 m^3. The conductivity was measured two and three days after the salt water was added to the septic tank. Measurements were done starting downstream, where lower conductivity was presumed, moving upstream so that samples with lower conductivity would not be contaminated. The results from the first round of conductivity measurements were inconclusive for the plastic part of the wetland. A second round of adding salt and measuring conductivity was therefore decided on, to conclude if the transport time for the plastic part was longer or shorter than that of the stone part. This time, the conductivity was measured after only one day, then again after two and five days.

5.2. Chemical and physical analyses

To evaluate the treatment efficiency of the wetland, water samples for chemical and physical analyses were taken from the observation pipes in the beginning and the end of the wetland, and in the septic and effluent tanks. All analyses were done at Centro de Aguas y Saneamiento Ambiental (C.A.S.A.), Universidad Mayor de San Simón, Cochambamba. The accuracy of the measurement methods is not known. Three rounds of sampling were done during two weeks in November 2008. For each round, three days passed between sampling in the upstream part and sampling in the downstream part of the wetland. There were also three days between each start of a new round. Samples were taken starting in the outlet, moving upstream and ending in the septic tank. This way there was no contamination of samples with dirtier water that could influence results. Sampling was done with a glass jar attached to a thin rope, from 0.4 m below the surface (at half the water depth). Instructions on sampling and sample preservation were given by C.A.S.A., and these were followed. Samples were always returned to C.A.S.A. within two hours of the last sampling time and they were stored in a dark, insulated box during transport.

5.3. Surface area

The porosity of each medium was measured. Measurements and calculations of mean surface area of the carriers were done on both stones and plastic pieces. An average stone was assumed to be spherical and completely smooth. Mean radius, mean surface area per stone and surface area per bed volume were determined. The plastic carriers are pieces cut from a deformed plastic tube. The inner wall is not smooth but ridged. The ridges were assumed to have the shape of small half circles which gave the maximum inner circumference. The minimum circumference was assumed to be an imaginary even circle. Using this, a surface area interval was calculated for the plastic pieces.

5.4. Water depth in observation pipes

Water level in the pipes was controlled using a tape measure and the glass jar on a rope. This was done to learn if the water depth was appropriate and to calculate the hydraulic gradient in the wetland.

6. Results and Discussion

6.1. Flow, retention time and tracer experiments

The minimum flow calculated was 0.54 m^3/day and the maximum flow was 1.49 m^3/day. In average, the flow was approximately 1 m^3/day (0.01 l/s). The mean nominal retention time for the whole wetland was 8.0 days for the plastic medium and 6.2 days for the stone medium.

Results from the tracer experiments can be seen in figure 2 a–b and figure 3 a–b. The average background concentration of specific conductivity was 1376 µS/cm according to the laboratory analyses.

In the results for the stone medium (figure 2a and 3a), the specific conductivity is increased and a "salt peak" moving downstream with time, is visible. The salt is spread out on both sides of the mass centre, the height of the peak decreases and the variance increases with time and distance from the source, probably due to dispersion and diffusion. According to the measurements the median transport time seems to vary a lot. Results from the first round of measurements show a median transport time of three days for the stone section. In the second round the median transport time is estimated through extrapolation to be around 20 days. The large variation in median transport time is likely to be related to differences in flow rate. During the second study the flow was considerably lower than during the first one, performed one month earlier. Possible water shortcuts and retardation processes are not supposed to change much during one month and are not likely the main reason for the large variation.

No salt peak could be seen in any of the results from the investigations of the plastic medium (figure 2b and 3b). The conductivity was even throughout the wetland and lower than in the stone section. Since no peak was visible the median transport time could not be determined. The most probable explanation for the lack of detectable differences in conductivity is that there is no, or just a little amount of water entering the plastic section from the septic tank. One reason could be that the inlet tube is clogged. Since the tubes are connected, both in the inlet and in the outlet like T-junctions, the flow can also be obstructed if the inlet or outlet pipes to the plastic chamber are located a little higher or lower than

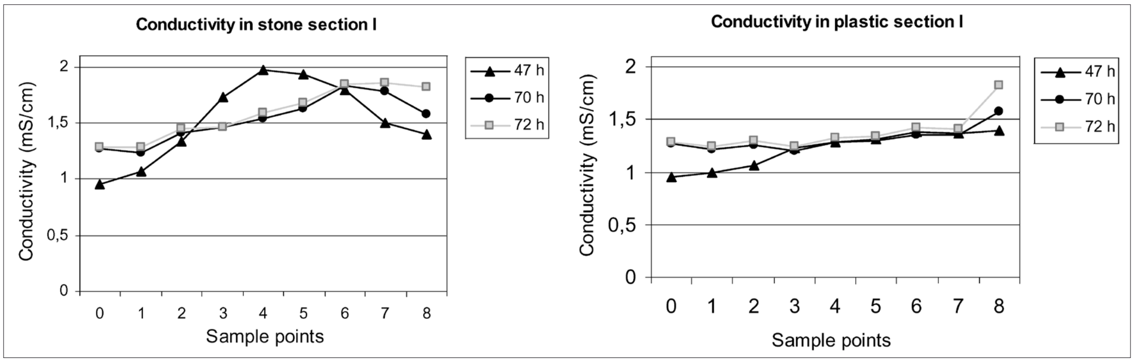

Figure 2 a and b. *Specific conductivity, measured during tracer experiment I, in 8 sample points in the stone (a) and the plastic section (b) of the wetland. The curves represent the conductivity 47, 70 and 72 hours after the salt was added. Sample point 0 refers to the septic tank and point 8 to the effluent.*

the stone chamber pipes. Another reason could be that the hydraulic conductivity is lower in the plastic medium. As a result, the water would flow mainly through the stone section. If the total flow entering the wetland goes through only the stone part, the nominal retention time is calculated to 3.1 days.

The density difference between salt water and fresh water is yet another possible explanation; denser salt water may sink below the fresh water in the chambers. All samples were taken from half of the total chamber depth, possibly resulting in conductivity levels being lower in the samples than at the bottom of the bed. If this was the case it should have influenced the stone section as well and is therefore not the most probable reason. To investigate the transport time in the plastic medium, the outlets of the two parts should be separated to prevent uncertainties about backwards flow. It is also necessary to control both inlet pipes and remove any obstructions. After these changes, new tracer tests can be done to determine a more accurate transport time.

Most HSF constructed wetlands referred to in the literature consist of one large chamber. For the design, idealised models like PFR and CSTR are used. Recent studies (Ascuntar Ríos et al. 2009, García et al. 2004) have shown that models with a series of tank reactors can fit experimental data from HSF wetlands without separate chambers, well. The wetland PTAR1 in San Antonio can be simplified to a series of tank reactors where each chamber is a CSTR. The results from the tracer studies (figure 2a and figure 3a) in the stone section are more similar to a retention time distribution curve for CSTR in series than for a PFR-model. All connections between the chambers in the wetland PTAR1 are placed to force the water to enter the chambers at different heights. Even if there were no complete mixing in the chambers, this design ensures a longer path for the water

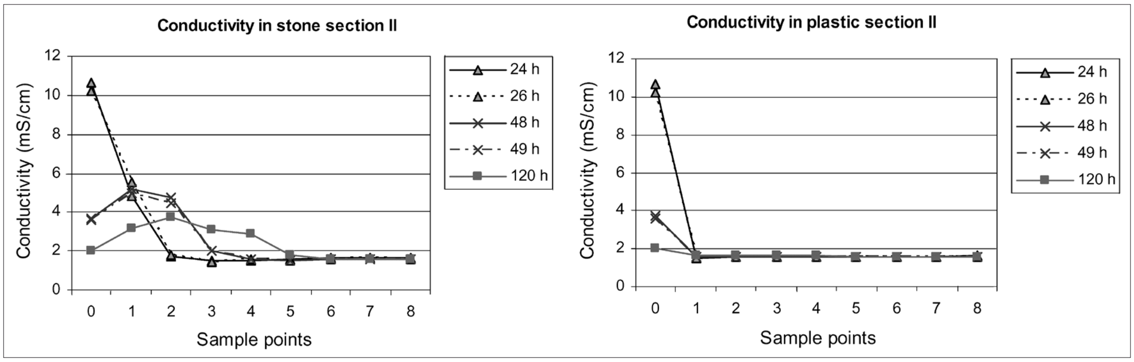

Figure 3 a and b. *Specific conductivity, measured during tracer experiment II, in 8 samples points in the stone (a) and the plastic section (b) of the wetland. The curves represent the conductivity 24, 26, 48, 49 and 120 hours after the salt was added. Sample point 0 refers to the septic tank and point 8 to the effluent.*

through the wetland than if the connections were placed at the same height. Hence, the worst case scenario, with no spreading at all in the chambers, still gives a longer retention time than a single wetland bed without internal divisions. The flow pattern in the chambers is unknown but dead zones could be expected in the two other corners of each chamber compared to where the connection pipes are located. Depending on the location of the connection pipes the flow pattern will look different. In chambers where the water enters near the bottom and exists near the top the flow moves against the gravity, resulting in lower water velocity and better treatment, compared to chambers where the connection pipes have the reverse position (Suliman et al. 2007).

6.2. Chemical and Physical Analyses

All results were roughly the same for both stone and plastic media. The laboratory analyses showed that pH was neutral and steady between 7 and 8, in all samples. Temperatures decreased as the water moved through the two sections, but remained in a range favourable to microbiological activity. Conductivity in both media was even through the whole plant and relatively high, just above 1 300 µS/cm. Irrigation using the treated water might affect some of the fruit trees, e.g. apple and lemon, since these plants could be more sensitive to the relatively high conductivity levels. Grass is not likely to be affected since grass species generally tolerate higher salinity levels and tolerance because of local soil and climate conditions, could have developed. When interviewing the gardeners, no negative effects from the treated water, on trees or grass, is reported.

Reduction of TS, DS and SS varies, and possibly improves slightly through the test series. PTAR1 shows a large reduction of BOD_5 and COD (figure 4). The reduction of BOD_5 is 80–97 % and the reduction of COD is 80–90 %, when comparing the septic tank and the outlet. The effluent level of BOD_5, for both stone and plastic, is mostly below the limit of 80 mg/l stated in Bolivian law (RMCH 1995). Reduction in turbidity is 50–80 %.

Total nitrogen and ammonia nitrogen are not significantly reduced in PTAR1. Instead, the levels increase slightly in the first and second round. In the last round the levels are more even, especially in the stone part. In general, levels are higher in the plastic part.

The BOD and COD levels decrease in the water on the way through the wetland according to all chemical analyses performed, but the concentration of nitrate does not increase in the downstream part of the wetland. In fact, the nitrate levels are low in all test results. The reason is probably the oxygen deficiency. Oxygen is needed for nitrification and the anaerobic environment in PTAR1 cannot be used by denitrifiers unless combined with an aerobic step. This leads to poor reduction in total nitrogen and ammonium nitrogen. Another reason for low nitrate levels is that if nitrate is produced in some part of the wetlands it can be consumed by denitrifying bacteria in other parts without being detected in the analyses.

Phosphorus concentrations vary and some are very high. Only in the second round there seems to be a reduction, both in total phosphorus and phosphate levels. In the other two rounds, there was no reduction and even an increase. Levels are in general slightly lower in the stone part. The P concentrations were, however, expected to be a little lower in the stone section because the stone bed contains soil residues which could improve P removal. The levels are, for some test rounds, lower in the stone section than in the plastic section, but conclusions are hard to draw. The anaerobic conditions also decrease the possible adsorption of phosphate. No better medium for P removal can be proposed without increasing the risk of clogging and surface flow due to low permeability in the wetland.

The slight increase in N and P levels that was observed in some of the rounds could be explained in different ways. Firstly the transport time of three days used to set the sampling interval, can be incorrect. The results from

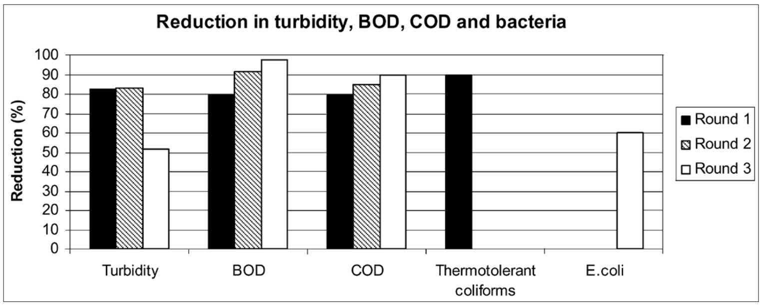

Figure 4. *Reduction (%) of turbidity, BOD_5, COD and bacteria in PTAR1.*

the tracer experiments indicate that the median transport time varies. If the same "water package" was not sampled both times, differences in influent concentrations could have been significant and made the results incomparable. There could also be an addition from dead plant tissue decomposing in the bed, and finally the accuracy in the laboratory methods is not known.

Oxygen should be transported down to the roots to keep plants alive, but there are disagreements in the literature on how much excess oxygen that is available for biological activity in the root zone of a constructed wetland. It is likely to be available only in small microzones around the roots and not diffusing to the whole bed profile. The results from the analyses for PTAR1 during November 2008 show that there is no dissolved oxygen in the water throughout the bed profile. The possible oxygen excreted by the plants, or diffusing through the medium or the observation pipes, is supposed to be in low concentrations and consumed quickly in decomposition of organic material.

There is no easy way of improving oxygen levels without redesigning the treatment system. One suggestion is to construct a vertical flow wetland before the existing tank. However, this solution might not be desirable since these systems need pumping to get good spreading of water and tend to be more expensive and technically more complicated. There would also be an open water surface which could lead to more mosquitoes and odour problems. A less expensive option is to intermittently lower the water level in the wetland or to alternate between two parallel beds. Any form of forced aeration is too costly in the poor areas of Cochabamba to be a viable solution. The reuse pattern is vital in making a good decision; if the recipient is a waterbody, the levels of nutrients like N and P are important to control in order to prevent eutrophication. In the case of PTAR 1, there is no stream or lake near the wetland. Irrigation is the best way to reuse water in this semi-arid region, and in this case the nutrient content is beneficial to the plants.

The total reduction of thermotolerant coliform bacteria is 90 %. The level to which the concentration has decreased in the 7^{th} chamber is equal in the plastic and the stone media, and the concentration of thermotolerant coliform bacteria was $8.0 \cdot 10^5$ CFU/100ml in the effluent, which is higher than the limit of 10^3 CFU/100ml for liquid discharge stated in the Bolivian law (RMCH 1995). The result for *E.coli* shows an effluent concentration of $2.0 \cdot 10^5$ CFU/100ml, which is higher than the recommended limits for unrestricted irrigation (WHO 2006a) but in the same magnitude as the recommended limit for restricted irrigation, $1 \cdot 10^5$ CFU/100ml (Blumenthal et al. 2000). The concentration of *E.coli* was reduced by 60 %. There are very few results since only one round of tests for thermotolerant coliforms and one round for *E.coli* were done. Water transport time in the wetland was not taken into consideration for the *E.coli* sampling round. Together, these facts make the results uncertain. Still, the treated water can probably be reused in the same way as today; for irrigation of lawns and trees in a limited area, at hours when the children do not have access to the lawns.

6.3. Surface area

The mean stone in chambers 2–5 has a surface area of 2 930 mm^2/stone. The surface area per plastic carrier was calculated to be 6480–8040 mm^2/plastic carrier, where the interval corresponds to the range from minimum to maximum inner circumference. When taking into consideration the measured porosity, 43 % for stone medium and 60 % for plastic medium, the surface areas per bed volume was calculated to be 110 m^2/m^3 and 420–530 m^2/m^3 for stones and plastic pieces respectively.

Interesting when discussing treatment capacity, is the surface area per bed volume. This measure is considerably larger for the plastic medium than for the stone medium, between 3.8 and 4.7 times larger. The surface area per bed volume of the plastic carriers is in the same range as the biofilm carriers produced by Anox Kaldnes (Anox Kaldnes 2009). The outside of the plastic carriers in PTAR1 is smoother than the surface of the stones, why it could be harder for microorganisms to grow on. Still, the major part of the surface area of the plastic pieces is inside the carriers. This inner surface is rough, promoting biofilm growth in a sheltered environment. Theoretically the plastic carriers have more capacity, with a larger surface area than the stones. This leads to more possible sites for microorganism activity and to a more extensive wastewater treatment. However, the analyses results do not show neither more nor less removal of BOD_5, COD, solids or bacteria in the part with plastic media. One explanation could be the possibly obstructed flow in the plastic section, changing retention time and influencing treatment mechanisms. Separated outlets from the wetland are recommended to further investigate which media is working best in this type of treatment plant.

6.4. Water depth

In general, the water depth is below the medium surface. No surfacing has been reported by the staff in the garden. On the measuring occasion, water depth was never less than 20 cm from the surface in any observation pipe. From the water level measurements and the 2 % slope in the construction, the hydraulic gradient was calculated to be 0.9 % in the plastic section and 0.7 % in stone section.

6.5. Constructed wetlands in Cochabamba

In Cochabamba, 76% of the town is connected to the central sewer system and municipal wastewater treatment plant (SEMAPA 2009). Already today there is not enough money to increase the treatment capacity of the treatment plant to the required level, even without adding any more households to the system. The plant is not big enough for the rapidly growing city and no solution is visible in the near future. In this situation, decentralized solutions, focusing on local recovery of water resources, are an economically viable alternative and complement to the centralized system. Many people living in the south part of Cochabamba are very poor and do not have the means to finance any major piping system on their own. They can, however, afford a low maintenance alternative, like constructed wetlands, that requires little energy, machinery or construction material.

New technology requires time to get used to, and there is some suspicion about the constructed wetlands as a good option to central systems or the old traditions. Visits to well functioning systems are a way to reduce public worries about inconveniences that any new kinds of treatment plants may cause. The results from PTAR1 and the attitudes from school and garden staff show that with information, education and "see-for-yourself", people with no previous experience can come to accept and appreciate this solution. Constructed wetlands can be shared among neighbouring households to treat wastewater from combined systems where water-flushed toilets are used, and greywater in areas where EcoSan-toilets (urine diverting dry toilets) are installed.

7. Conclusions

The general quality of the effluent water from PTAR1 is improved but it is still unfit for many uses. The relatively low effluent quality highly limits the application possibilities. Only three test rounds were made and this reduces the reliability of the results. The analyses results can, however, be a good indication of the treatment capacity of PTAR1 and the general levels of the different parameters tested. The water is fairly clear and the reduction in BOD_5, COD and turbidity is acceptable. The wetland is largely anaerobic which is likely the reason why no nitrogen removal was observed. A low reduction in nutrients is mostly a problem if the water is let out into a lake or river. Here they fertilize the crops and grass that are irrigated with the water. Re-use of the treated water is beneficial since the area is very dry. In the school and garden it can be put to good use. Today there is a problem with excess water that is let out onto the street. Reduction of bacteria in the wastewater is mediocre and the effluent water contains high amounts of bacteria and should not be discharged without protecting humans and animals that might come into contact with it. The excess water could be used in the garden or infiltrated into the ground in the garden instead. The first option is better since the water is reused and not wasted.

In general the results are similar for both plastic and stone media. Without knowing anymore about the flow within the plastic section, it is hard to say anything about if the treatment capacity in the plastic section is higher in reality than shown in the results. To better see which material is superior, the outlet of the wetland should be separated into two outlets and new measurements should be made. Other examples of improvements to the treatment capacity are to plant new macrophytes where the original ones have died and to install a sandfilter after the wetland, to further reduce solids, BOD and bacteria. If new treatment plants of this type are constructed, they should be designed to reduce the effluent bacteria level far below the requirements in the Bolivian ordinance and the WHO guidelines. In that way there are less health risks even if the water quality fluctuates. PTAR1 has probably not yet reached its final capacity, and further tests are needed to monitor the development of the plant. Treatment capacity could change while microorganisms and plants establish properly. The wetland is built as a pilot plant, and to investigate the development of the wetland more thorough analyses are needed.

Cochabamba has a long dry season, creating a great need for water reuse and especially for irrigation of agricultural and recreational areas. Treated water from constructed wetlands can be used for this purpose, reducing the consumption of potable water, shortening water transports, reducing the risk of eutrophication in adjacent waterbodies and lowering energy requirements. Climate and terrain conditions in Cochabamba are suitable for constructed wetlands. HSF constructed wetlands require little energy, construction material and maintenance. They are a good complement to centralized wastewater treatment in sparsely populated, low-income areas like peri-urban Cochabamba. Use of constructed wetlands could lead to more green areas with lawns and trees, which in turn decreases soil erosion.

Acknowledgements

The authors would like to thank AGUATUYA for providing practical help during the field study and C.A.S.A. for performing the analyses. Especially thanks to the supervisors in Bolivia, Gustavo Heredia and Marcelo Ledezma. The authors thank Christian Bomblat, Abel Lizarazo, Alberto Melgar, Oscar Medina and Martha

Müsch for valuable information about the water and sanitation situation in Cochabamba. This study was made possible by grants from the Swedish International Development Cooperation Agency (SIDA), within the framework of the Minor Field Studies Scholarship (MFS) Programme, and Ångpanneföreningens Forskningsstiftelse, whose support is gratefully acknowledged.

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