Evaluation of sanitation and wastewater treatment technologies: case studies from India

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Abstract: This paper reports about the results of an evaluation of sanitation systems in India. The following sanitation systems were evaluated: septic tanks, communal ecosan systems, biogas toilets, solid immobilised biofilter, multiple stage filtration and DEWATS. The evaluation has been based on an initial assessment looking at whether the systems comply with their intended benefits, and more in depth evaluations on cultural, economic and/or hygienic aspects where the initial assessment has not provided sufficient knowledge.

INTRODUCTION

It is well known that worldwide there is a large gap in developing countries with respect to the provision of adequate water supply and sanitation facilities and services. Despite major efforts still only little progress has been achieved, varying between countries. Recent surveys (WHO-UNICEF, 2008) have shown that in 2008 worldwide still around 1,1 billion people have practiced open defecation. In particular in South Asia open defecation is prevailing. Two out of every three Indians defecates in the open, which means 665 million people lack improved sanitation (WHO-UNICEF, 2008). India is thereby the country with the highest number of people who practice open defecation.

Traditional latrines, which are widely spread in the country, are the first step to manage excreta. The next step in the sanitation ladder is any form of improved latrines that ensure more hygienic separation of excreta and the final step is a flush latrine connected to a septic tank or a sewer network. Each successive step of the ladder represents a higher unit cost but are assumed to give a correspondingly lower level of health risk (Morella 2008). In this study, different sanitation levels, from septic tanks to decentralized treatment chains including as well anaerobic as aerobic treatment of wastewater have been studied.

The Indian National Urban Sanitation Policy (NUSP 2008) already recognized the need to consider various factors when implementing a new sanitation system as often people are not ready or willing to adopt these and pay for service provision. The technologies are linked to a whole set of environmental, behavioral and cultural parameters that need be taken into account. A holistic approach is required for technology choice. Therefore, certain criteria and indicators have to be applied. Some studies already dealt with the definition of a core set of indicators that are applicable for different sanitation and wastewater treatment technologies (Jones 2009, Singh 2008).

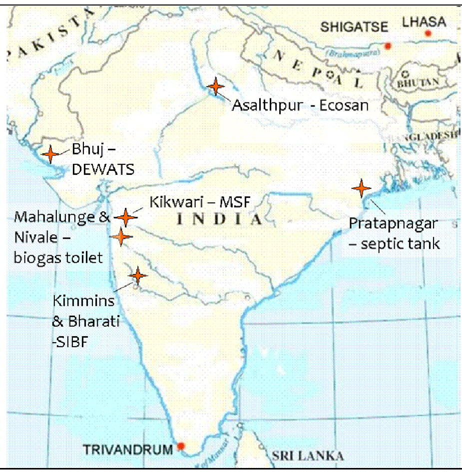
This paper presents the result of an evaluation of selected sanitation and wastewater treatment technologies across India. In this study a pragmatic approach was used to assess the technologies. Rather than setting up an evaluation framework comprised of a number of criteria and indicators which then is applied uniformly across all case studies, the indicators and criteria used for the evaluation were defined in a bottom up way for each selected technology, following the methodology described below. Reasons for success as well as factors for failure were analyzed and crucial aspects for the successful implementation of sanitation and wastewater treatment technologies were identified.

DESCRIPTION OF SANITATION SYSTEMS

Different types of sanitation systems and decentralized wastewater treatment plants have been studied: septic tanks, communal ecosan systems(UDDT), biogas toilets, solid immobilised biofilter, multiple stage filtration (MSF) and Decentralized Wastewater Treatment System (DEWATS). Table 1 shows the different technologies and their location.

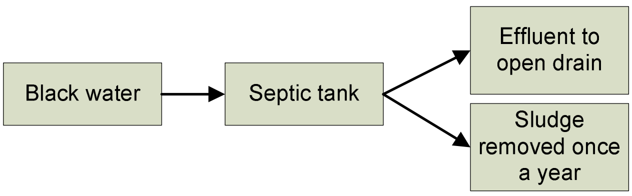
Table 1: Overview of studied sanitation systems

Type	
Septic tank	individual
Ecosan (UDDT)	communal
Biogas toilets	individual
Solid Immobilised Biofilter (SIBF)	communal
Multiple stage filtration (MSF)	communal
DEWATS	communal



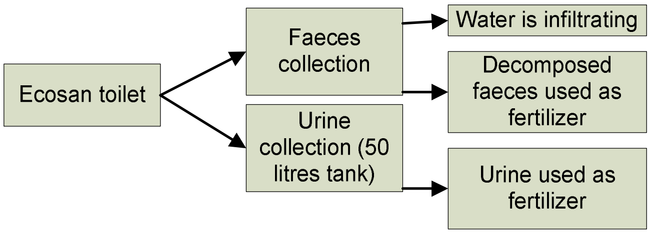
Septic tank

The septic tanks were constructed in 2003/04. This technology is widely spread in states like Uttarpradesh and Bihar. The systems have a standard design are constructed by local masons. The black water is collected in the septic tank which is connected to the storm water drainage. The sludge, which settles in the bottom, is removed once in a year.



Ecosan (UDDT)

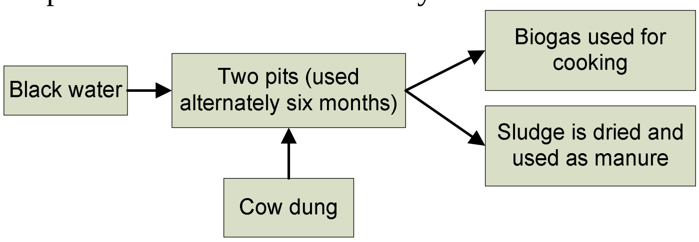
The communal Ecosan toilet in Asalthpur has been constructed by a NGO in 2005. It should help the villagers to save the cost of chemical fertilizers by using manure produced by the Ecosan toilets and also served as a more hygienic option for the villagers compared to open defecation which the majority practiced before. The communally used Ecosan model in Asalthpur consists of two separate pits for the urine and the faeces. After one pit is full the contents desiccate for six months whilst the other pit is used. After defecation the user applies one hand full of ash on the excreta. Urine is stored in the urine collection chamber, from where it is collected and used directly as a natural fertilizer.



Biogas toilets

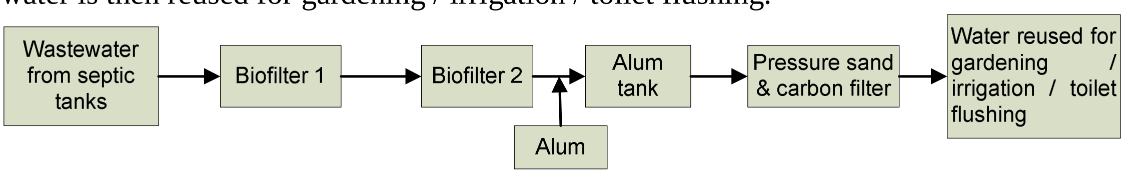
In both case study sites, Mahalunge and Nivale, the first biogas plants were introduced in the mid 80`s with the main objective to use cattle dung for the production of biogas. The motivation to connect the biogas plant to the toilets came from the Government of Maharashtra’s Clean Village Competition. The households converted the existing biogas plants in two pit toilets and constructed additional biogas toilets. The system consists of household toilets with offset twin pits outside. Construction material could partly be found (bricks) or produced (concrete ring, pan) locally. As it is a wet toilet system, faeces are flushed away with water. There is an additional inlet where the cow dung is mixed with water. This cow dung slurry is transported to pit through clay pipe.

In the pit flushed away faeces are left for decomposition. During decomposition the released methane gas is captured and the outlet is directly connected to the kitchen for use. The slurry of the pit is used as manure when dry.



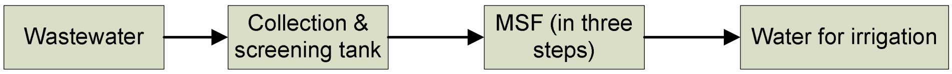
Solid Immobilised Biofilter (SIBF)

The SIBF were constructed in schools in 2004. Bharati and Kimmins are located within a tourist area and the Maharathtra Pollution Control Board (MPCB) made it mandatory for schools, hotels and other institutions to dispose their waste in a proper manner. MPCB checks once in a year whether this has been achieved. The wastewater from the septic tank is collected in the collection tank. From the collection tank, the wastewater is pumped to biofilters 1 & 2 through pumps. After passing through biofilter 2, alum is added and the solid material settled. From the settling tank the water is pumped to pressure sand filter and activated carbon filter. The final treated water from the activated carbon filter is then chlorinated and stored in the treated water tank. This treated water is then reused for gardening / irrigation / toilet flushing.

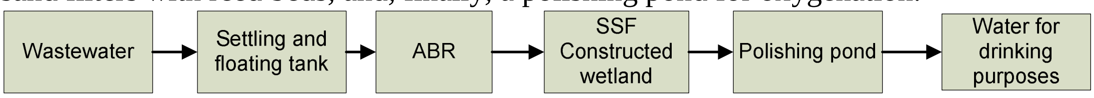


Multiple stage filtration (MSF)

This system was implemented in 2002 in Kikwari, which is a village of 1.750 inhabitants. Due to little precipitation, it is difficult to conduct agricultural activities. Therefore, a treatment plant has been constructed with the aim to reuse the effluent for irrigation. The wastewater is first screened and stored in a tank for about one day by which the impurities settle down in the tank. Then the water is passes to a filter tank, where it is filtered in three stages (using different types of sands and bricks). After that, the treated water is collected in another tank, from where it is supplied to a fruit farm in the form of drip irrigation.



Decentralized Wastewater Treatment System (DEWATS)
This case study is comprising a wastewater treatment that is treating the wastewater of a colony of 650 people. It was constructed by the Hunnar Shaala Foundation in 2004. The water is used for irrigation of the surrounding green belts. The system consists of a primary treatment system with a settling and floating tank, a secondary treatment system of an up-flow type baffled reactor which digests wastewater anaerobically, a tertiary treatment in subsurface horizontal flow (SSF) sand filters with reed beds, and, finally, a polishing pond for oxygenation.



The five evaluated technologies represent different levels of sanitation services. Whereas the septic tank aims only at providing better hygienic conditions, the ecosan and biogas systems provide additional benefits (reuse of nutrients, biogas). The decentralized systems aim at reusing the treated wastewater for irrigation. Table 2 shows the intended benefits for the case study systems.

Table 2: Intended benefit

Intended benefit	Basic sanitation			Wastewater treatment		
	Septic tank	Ecosan	Biogas toilets	SIBF	MSF	DEWATS
Better hygienic conditions	X	X	X	X	X	X
Reuse of nutrients, biogas	NA	X	X	NA*	NA*	NA*
Reuse of treated wastewater for irrigation	NA	NA	NA	X	X	X

* treated water used for irrigation

METHODOLOGY

The assessment conducted first an initial assessment. The initial assessment evaluated the performance of the technology. Appropriate indicators were chosen (e.g. water quality indicators, indicators for acceptance, hygienic indicators, etc.) in order to assess whether the technology meets its intended benefits. For case studies which have not met their intended benefits or for which (non-acceptable) risks have been identified, more detailed investigation was conducted, such as e.g. additional hygienic or a socio-cultural studies. For the socio-cultural evaluation the the recipients' willingness to use the technology, their acceptance after implementation and during use, and the reasons for mal-use were evaluated. Questionnaires formats and coding of responses were organized following the agenda provided by the Receptivity framework (Jeffrey and Seaton, 2004). In the socio-economic assessment respondent were asked about their perception of their current service level, their level of satisfaction, expectations for the future and their willingness to pay for improvements. The hygienic assessment built up on experiences in previous work such as Schönning et al (2007) or Stenström et al. (2006).

RESULTS

Septic tank

Result of initial assessment

The evaluation of the technology has shown that it was partly a failure case: The system is mal-functioning, but accepted as no other option is available. Initially the family members used to practice open defecation, now this is stopped and they use their own household level toilet. Users are satisfied with the system, but the disposal of the wastewater/sludge poses a health risk to the users as the emptying has to be done manually near the road. Additionally it poses a health risk to the overall community and especially the children that will come into contact with the water.

Reasons for failure

The draw back of this technology is that the accumulated sludge in the tank has manually to be emptied and is discharged to road which is resulting in sever hygienic risks (see below). The system itself is well accepted and the family members, who used to practice open defecation in the nearby railway track before, now stopped this practice and use their own household level toilet. The new system is also safer against violence for women as they do not have to leave their house during night time anymore.

Hygienic assessment

The system results in a high exposure for the persons emptying it accompanied with a high risk. Around 80% of the villagers suffer from water-borne diseases like stomach and skin problems. The system further enhances the exposure, especially of children from the open drainage ditches. It further enhances the risk of mosquito breeding and thereby of filariasis. The nearby collection pond, in which the effluent discharges shows total coliform counts of 1512/100 ml and feacal coliforms of 118/100 ml. Microbiological contamination could also be detected in the water from handpumps, which indicated that also the groundwater becomes contaminated. However if this was due to the effluents from the septic tanks or comes from other sources is presently unclear. The system needs immediate attention.

Socio-economic assessment

Septic tanks had construction costs of INR 18.000 per unit and the time for construction required 15 working days. Some users stated that they think that the costs were high; the remaining interviewed users thought that it was not so expensive to construct these schemes. All respondents said the costs were affordable or even easily affordable. All users of septic tanks think that they will stay with their current service in the future. However, due to the water borne disease a family looses 25-30 working days per annum both male/female that results in loss in income of INR 3000 for males and INR 500 to INR 1000 for females.

Ecosan

Result of initial assessment

The evaluation of the technology has shown that the communal toilets are partly a success case. Open defecation has been reduced, but still not all villagers use toilets. The water consumption has been reduced to one litre per toilet use and fertilizer is applied to grow paddy.

Reasons for success:
Urine and manure are used for growing paddy. Every six months 500kg of fertilizer are applied on the farmland. Only one liter of water is used for anal cleansing and hence saves almost 10 to 12 liters of water. The toilets are well functioning, but from 200 targeted people only about 80 people use it (the others still do open defecation). Therefore, socio-cultural issues were further investigated:

Socio-cultural assessment
The problems with the toilet may be rooted in overuse – there is an average of 27 people using each toilet. The Sphere Project (2004) recommends a maximum of 20 people per toilet in emergency situations. In a development context, an even lower number of people per toilet would be expected. The high number of people per toilet will contribute to odor, and the small number of toilets for a large population will mean than some people will have to walk a long way to use the toilet.
All households where some or all of the household members used the toilet had received training from the local NGO. Of the four households that did not receive the training, two had no users of the toilet, and the other two had some users of the toilet.
The level of satisfaction among users was investigated: 50% of respondents considered themselves satisfied with the system, expressing a feeling of relief for not having to practice open defecation. Furthermore, 33% of respondents considered the toilet positive for their health. Users showed willingness to invest to improve the status of the toilets (44.5%), such as paying for disposal of excreta.
Users' understanding of reuse components of the Ecosan of the technology was explored: 44.5% of the sample investigated agreed that there was a potential to use urine as soil conditioner, and the use of human excreta as soil fertilizer. The remaining respondents were not sure about the possibility or preferred not to answer.
Among all respondents (both users and non users) 72% reported to have experienced problems with the Ecosan toilet. Multiple responses analysis was computed to identify the most common problems experienced. These are presented in Figure 1, below.

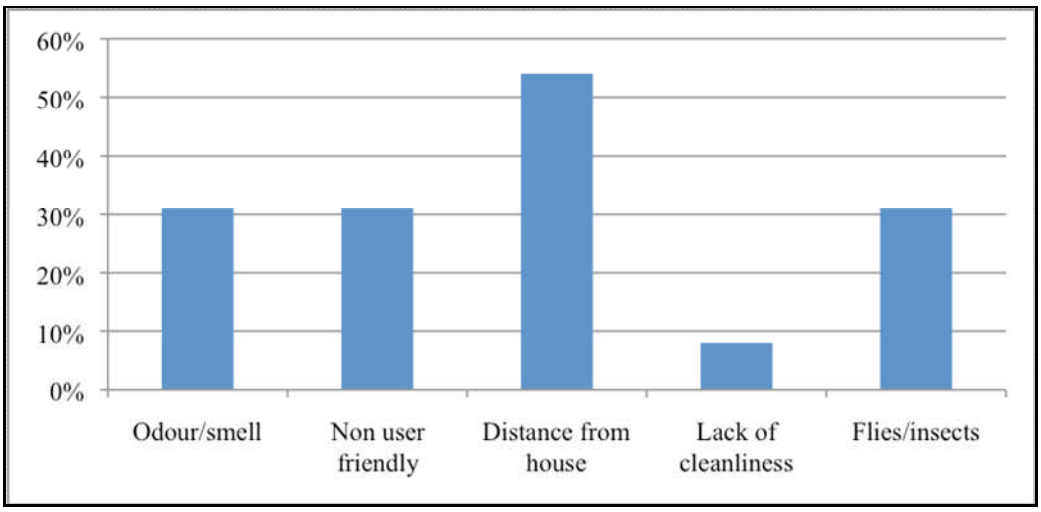


Figure 1: Identified problems with Ecosan

Households where some or all family members used the toilet had a positive problem solving attitude, with 70% reporting the problem to the NGO

Users' behaviour in using the Ecosan toilet was also explored. 38% of respondents said they diverted urine in the appropriate chamber, whilst 61.5% stated that they do not divert urine. However 50% of users always covered their faeces with ashes after defecation.

Hygienic assessment

The user is largely unexposed to the contents of the dehydration vault but may be exposed during maintenance in leveling out the faecal cone in the vault and during emptying.

Both for sitting and squatting the floor of the toilet (e.g. the slab or the area around the pedestal) can act as an exposure pathway as excreta can be transferred to the hands or feet. After defecation the user washes his back using half a litre of water in an area provided for it inside the room and this water is collected and diverted to a nearby field through a pipe. The user or the person responsible for cleaning may be exposed to faeces which may be deposited in the urine area and which must then be removed. Normally the risk of exposure from flies or other insects are low. If the material is properly covered and the pit is vented, exposure to flies and other vectors is minimized considerably. The urine should be diverted to ensure proper functioning of the dehydrating vault. The technical design and user's perception largely govern the degree of faecal cross-contamination and the subsequent risks of accidental direct exposure. The urine collection container should ensure that overflow does not occur, which may also lead to accidental direct contact.

Biogas toilet

Initial assessment

The evaluation of the technology has shown that it was mainly a success case. Biogas toilets have been built by each household for disposal of human excreta. The entire village is open defecation free as all households are using the toilets. Each house gets around 3- 4 hrs of cooking gas. It also depends on how much cow dung is augmented and the family size. The pipes from which the gas is transported to the house are properly mounted. The pressure valves are well maintained. Some households have cooking gas linked toilets some have only toilets

The amount of slurry is very limited; it does not cause any unhygienic condition. After drying the slurry is converted into organic fertiliser. A separate ditch is dug for waste slurry collection. The ditch is well covered with dried grass. The operation and maintenance cost is almost negligible

Reasons for success

The technology was implemented by the households on own initiative and costs. The village is free from open defecation and people accept as well the toilets as the generated biogas. Normally one family gets four to five hrs of cooking gas from human excreta. This reduces their burden on gas cylinder which they had to purchase from the market. However, some people do not accept to use the gas for cooking for religious reasons (this applies only to 3-4 households out of 51).

Hygienic assessment

Contact with the slurry is the most dangerous exposure pathway. Because the slurry is free-flowing it is often allowed to pour out of the reactor into a ditch directly on the land and sometimes directly to agricultural areas where then additional exposure may occur for people in direct contact with the material and for consumers of products fertilized with it. Even if partially treated the slurry is unsafe and any type of exposure should be avoided. Frequency of exposure is high-medium for the user, depending on the slurry production and outlets and low - medium for the community, depending on slurry containment and outlet areas. The 'Level of risk' is medium for the user, and for the community and may be elevated for the consumers of the products depending on the holding time in the reactor and the drying time of the slurry before use.

Socio-economic assessment
Biogas toilets costed at the time of construction about INR 10.000 (nowadays costs are up to 50.000 INR) and construction time needed for biogas toilets is about 18-20 working days. All respondents said the costs were affordable or even easily affordable. Some users of stated that they would need some support for maintenance and estimated their current effort for O&M on ~1hour per week. The biogas systems deliver only enough biogas if the family consists of 10 or more members, which seems to have been the case for the majority of the interviewed households.

Solid Immobilised Biofilter (SIBF)
Results of initial assessment
The evaluation of the technology has shown that it was mainly a success case. The effluent complies with Indian norms, with values of 6 mg/l BOD and 20mg/l COD, and the water is reused for irrigation of the school garden and toilet flushing. The system is working well and O&M costs are ~3 IRs.per m^3 treated water (compared to 20 IRs. for conventional treatment).

Reasons for success
A main reason for this is seen that the entire O&M is taken care of by a company. And the costs charged by the company for O&M are reasonable for the school. The users are very satisfied with this technology because the treatment system is serving the intended purpose. The treated water is being reused for gardening and toilet flushing thus conserving the precious water.

Hygienic assessment
The main risks relate to the maintenance work, the irrigation and the contact with irrigated areas and produce, but as the treated water conforms not only with the norms for irrigation, but also with the surface water discharge standard, the risk for the operator is low. Moreover, disinfection is also done before the reuse of this water. This water while used for gardening infiltrates through the soil naturally and is not put directly into the aquifer. The risk related to reuse in gardening and groundwater recharge is judged as low.

Multiple stage filtration (MSF)
Results of initial assessment
The treatment plant does not show any technical problems and users are satisfied to have this technology, which provides water for irrigation. However, on the spot sampling has showed high organic contamination and hence that the treated water did not meet the standard for irrigation (see below). There is also no regular water testing to ensure whether the discharge norms are complied with.

DEWATS
Results of initial assessment

The system is a success case. It is accepted by the users and performs well (effluent quality: BOD: 17 mg/l, COD: 50 mg/l, Oil and grease:4 mg/l, pH: 8.0 – 27.2.2009).

Reasons for success
The system is well functioning, well used, and managed by the community. The users are collecting money for the maintenance of the system. The construction costs for one DEWATS systems (the one discharging to the green belts) were approximately IRs. 14.500.000: these costs are for all treatment steps. In the last two years O&M costs were ~ Rs. 1500/- per month: these costs cover the labour costs (needed to dispose the sludge of primary and secondary treatment steps and to maintain the plants of the tertiary step).

Hygienic assessment
This is an example of a well-designed system with little hygienic risks. Further risk reduction may be ensured by appropriate irrigation practices and crop selection.

Comparison of Indian wastewater treatment standards with performance of treatment plants
For illustration purposes, on the spot samples have been taken to show how the treatment efficiency relates to the Indian standards. There exist different standards depending on the further use of the effluent. For discharge into inland surface waters, the standards are more stringent as for reuse of effluent for irrigation purposes. In all three treatment plants the effluent is reused for irrigation, but the SIBF and the DEWATS also comply with the standard for discharge into surface waters. The MSF does not comply with the two standards.

Table 3: Comparison of standards (issued by the Central Pollution Control Board) with effluent values

	Standard for discharge into inland surface waters	Standard for reuse of effluent for irrigation	SIBF effluent (Kimmins) *	MSF effluent*	DEWATS effluent **
BOD (mg/l)	30	100	6	197	17
COD (mg/l)	250	NA	20	688	50

* one-time samples taken in 2009
** existing information provided by the Hunnarshala Foundation-Bhuj

CONCLUSIONS AND RECOMMENDATIONS

All systems are well accepted except of the communal Ecosan toilet, where users complained about the far distance to the systems. The hygienic risk is highest for septic tank due to the high risk for direct contact during emptying and directly to community members as well as where the pond, in which the septic tanks discharge as well as the water from handpumps shows contamination. The biogas and Ecosan system pose medium risk to the person who is emptying the systems, whereas the SIBF and the DEWATS feature only low risk as users do not get in direct contact with the system. The risk is here dependent of the reuse irrigation practices, type of crops and how well the prior treatment has worked. Also in the MSF users do not get in direct contact with the wastewater, but as the effluent did not comply with Indian norms for irrigation. The biogas generated in the biodigesters can be used for cooking and SIBF and DEWATS produce effluent that is suitable for irrigation.

Based on the results of the assessment the following conclusions and recommendations can be made:

- All on-site sanitation systems except of the ecosan system were individual systems and well accepted by the users. The main constraint of the ecosan systems is far distance to the toilet systems, which should be considered when building communal systems.
- Respondents' suggestions of improvements of the systems should be taken into account by engaging in a dialogue with users to understand their needs and discuss feasible interventions.
- Education on appropriate hygiene practices as well as the use of the systems as a way to improve aspects, such as smell and breeding insects, should be provided on an ongoing basis.
- In the two evaluated household on-site systems, biogas system and septic tank, the main risk is the sludge, which is difficult to handle. Professionally equipped workers are necessary to conduct the emptying of biodigester and the septic tank.
- To assure that safe products are obtained from the biodigester, temperature has to be high enough. In situations where both the heating and hydraulic retention time cannot be fulfilled, it is important that the product is treated further either in co-composting or with standardized drying.
- There exist successful examples for decentralized wastewater treatment systems aiming at reuse of the treated wastewater
- One factor of success of the decentralized systems is the well organized operation and maintenance, which is either conducted by a private company or a community committee. Another prerequisite is the coverage of operation and maintenance costs, which has been achieved in the case studies due to community contributions. Those decentralized systems also require less energy (and have therefore lower costs) than conventional treatment systems.
- Whereas the performance of the SIBF and DEWATS is controlled on a regular base by MPCB and the Hunnarshala Foundation, the efficiency of the treatment is not tested in the MSF system in Kikwari. As all systems provide water for irrigation with which users get in contact, regular monitoring is required to keep the hygienic risks low.

ACKNOWLEDGEMENTS

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