22 Potential and Limitations of Decentralised Wastewater Management in Southeast Asia

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Abstract

In rapidly growing cities of Southeast Asia, decentralised technologies for wastewater treatment have a great potential for mitigating the problems of water pollution and water scarcity. This article synthesises research conducted in Thailand, Vietnam and China with the aim of identifying the potential and limitations of introducing decentralised approaches into domestic wastewater management in the region. Laboratory and pilot-scale research on anaerobic baffled reactors (ABRs) and constructed wetlands (CWs) in Thailand and Vietnam revealed that decentralised wastewater treatment technologies can treat domestic wastewater to satisfactory levels at reasonable costs. While the benefits of a decentralised approach are widely recognised within the international scientific community, very few systems are actually implemented in Southeast Asia. Barriers to wide-scale recognition and application of decentralised systems are manifold. Many policy- and decision-makers do not yet perceive decentralised wastewater management as state-of-the-art, indicating technical limitations and a lack of public acceptance as the main obstacles. This lack of political commitment hinders the creation of enabling institutional and legislative frameworks. A basic lack of capacity to plan, implement and operate systems was also identified as an important barrier to wide-scale application and sustainable management of at-source pollution control measures in Southeast Asia. While the limitations are known, measures to overcome these barriers are far more complex. An enabling environment must be created by raising awareness of the importance of wastewater management and of opportunities such as decentralised approaches, creating supporting policies and regulations, identifying suitable financing mechanisms and incentives, and building capacity to plan, implement, operate and maintain such systems.

Keywords: Pollution control at the source; decentralised wastewater management; anaerobic baffled reactor; constructed wetland; enabling environment; Southeast Asia.

22.1 Introduction

The provision of adequate water and sanitation services is one of the oldest and most fundamental challenges in the urbanising world. Historically, most Western countries have relied on sewer systems with centralised wastewater treatment plants optimised for water pollution control. For a long time, it was generally accepted that this model could be exported to any part of the world. While the conventional approach to urban environmental sanitation has contributed greatly to the improvement of hygienic conditions in industrialised countries that could afford to install and operate these systems, it is now generally recognised that under certain circumstances, this 'end-of-pipe' strategy leads to failure (Larsen and Gujer 2001; Zurbrügg et al 2004). In most cities in Southeast Asia, only a small part of the wastewater collected in sewer lines is treated. In Kunming, China, for example, despite large investments in centralised treatment plants in the last decade, only 25% of wastewater collected in the city sewer system is treated, with most of the untreated remainder entering Dianchi Lake – the main drinking water source of the city – via overflows (Huang et al 2006). It was further simulated that even the application of the best available technology – upgrading of the city's urban wastewater collection and treatment system to up-to-date standards – could not prevent lake eutrophication. Indeed, simulations showed that only a combination of innovative measures could solve this problem.

There is a growing tendency to argue that decentralisation of wastewater management would be more effective than centralised systems. In general terms, decentralisation may be defined as a transfer of the authority, functions, resources and responsibilities of government, management or administration from the national (central) level to 'sub-national levels', including lower levels of government, administrative field offices, the private sector, NGOs representing the community, and the community itself. Decentralisation of wastewater management relates to planning and decision-making, design of physical infrastructure, and management arrangements for operations and maintenance (Parkinson and Tayler 2003). The decentralised approach offers important benefits, namely the possibility of dealing with wastewater locally and applying pollution control measures at the source. By tackling pollution problems close to their source, the large capital investment required for trunk sewers associated with centralised systems can be reduced, thus increasing the affordability of wastewater management systems. In terms of planning, decision-making and management, a decentralised approach makes it possible to devolve responsibility from centralised institutions to lower operational levels, promoting partnerships between community groups, private sector organisations and government agencies. These partnerships increase local accountability, provide greater opportunities for community participation, and can result in a service that is more affordable and responsive to the needs and demands of local stakeholders (Strauss and Montangero 2003).

Despite the above-mentioned opportunities, pollution control measures at the source are not yet fully recognised as an alternative to the conventional centralised wastewater management approach. The present article synthesises the outcomes of a series of research projects conducted within the framework of the Swiss National Centre of Competence in Research (NCCR) North-South programme that aimed to determine the technical potential of promising decentralised wastewater treatment systems and identify the main barriers to their wider implementation in Southeast Asia.

22.2 Methods and approaches

The treatment potential of technologies for domestic wastewater treatment was assessed based on a review of different NCCR North-South related projects. The review focused on the anaerobic baffled reactor (ABR) and constructed wetlands (CWs) for the pre- and post-treatment of domestic wastewater, respectively.

The ABR is a technically modified septic tank, which is the most commonly applied method for on-site treatment of domestic wastewater in Southeast Asia (Nguyen et al 2007). The ABR differs from the conventional septic tank system in that it is operated in an up-flow mode, resulting in both improved physical removal of suspended solids and improved biological conversion of dissolved components (Figure 1). While the ABR was suggested by several researchers as a promising system for the treatment of high-strength industrial wastewater (see Barber and Stuckey 1999 for a comprehensive review), its applicability for the treatment of low-strength domestic wastewater in tropical conditions is not well documented.

The CW is a natural wastewater treatment system that combines multiple treatment modules, including biological, chemical and physical processes (Babatunde et al 2008). The technology has been successfully used for the treatment of a wide variety of wastewaters, including domestic wastewater,

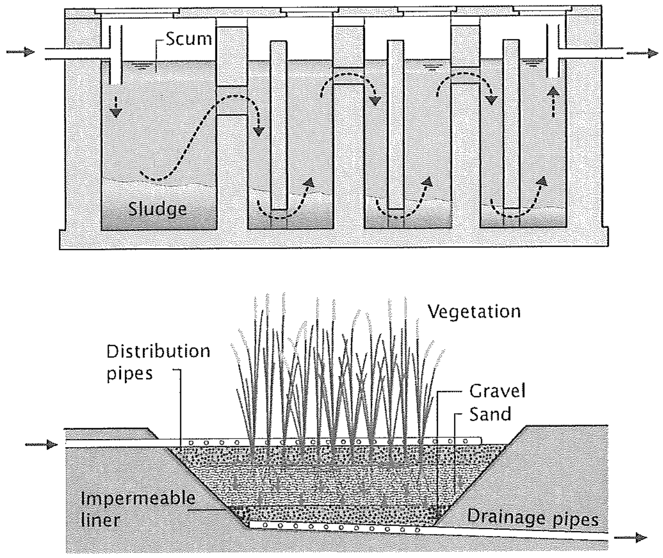

Fig. 1
The two wastewater treatment technologies investigated: Anaerobic baffled reactor (ABR, top) and vertical-flow constructed wetland (CW, bottom). (Source: Morel and Diener 2006)

industrial effluents, urban and agricultural storm water runoff, animal wastewater, and faecal sludge (Kadlec et al 2000; Mbuligwe 2004; Koottatep et al 2005). Until recently, however, knowledge about how wetlands work in Southeast Asia was not sufficiently advanced to provide engineers with detailed guidance. Our review focused on the treatment efficiency of these systems in terms of organic load (expressed as chemical oxygen demand [COD] and biochemical oxygen demand [BOD]) and nutrient removal (phosphorus, nitrogen). The exact methodology of the various experiments is described elsewhere (Khumkhom 2004; Koottatep et al 2006; Nguyen et al 2007; Sarathai 2007) and not further discussed here. Table 1 provides an overview of the projects reviewed for the present synthesis.

Institutional, legislative and socio-economic barriers to the wide-scale application of innovative technologies for pollution control at the source were analysed based on one case study in Kunming, China, and on interviews with governmental agencies and sector specialists in Thailand, Lao PDR and Vietnam. Medilanski et al (2006) relied on expert interviews adapted from Meuser and Nagel (1991) and Witzel (1982) to identify the attitudes of the most important stakeholders in Kunming towards different measures at the source for more effective wastewater management. Thirty-four interviews were conducted with stakeholders from political, administrative, scientific and business circles. The priority and feasibility of different measures at the source were evaluated based on structured interviews. The exact methodology of this study was presented elsewhere (Medilanski et al 2006) and is not discussed any further at this point.

22.3 Results

22.3.1 Anaerobic baffled reactor (ABR) and constructed wetland (CW) technologies

The projects on ABR and CW reviewed in this article (Table 1) provided scientific evidence for treatment performance and critical design parameters of these two wastewater treatment technologies, as well as valuable knowledge about their costs and the operation and maintenance requirements of the systems.

The anaerobic baffled reactor – an efficient, robust and cost-effective technology for the pre-treatment of heavily polluted domestic wastewater: The ABR has several advantages over well-established systems such

Table 1

Projects on decentralised wastewater treatment technologies reviewed in this synthesis article.

Project	References
Laboratory- and pilot-scale research on anaerobic baffled reactor (ABR) and constructed wetland (CW) in Hanoi; conducted by the Centre for Environmental Engineering of Towns and Industrial Areas of the Hanoi University of Civil Engineering (CEETIA/HUCE) and the Swiss Federal Institute of Aquatic Science and Technology (Eawag) in collaboration with Linkoping University, Sweden, and the Vietnamese Ministry of Natural Resources and Environment (MONRE), 2003–2007	Beauséjour and Nguyen 2007; Nguyen 2007; Nguyen et al 2007; MOC, in preparation
Pilot-scale research on ABR and effluent polishing systems (CW, anaerobic filter and sand filter) in Bangkok; conducted by the Asian Institute of Technology (AIT) and Eawag in collaboration with the Thai Pollution Control Department (PCD), 2003–2005	EEM/AIT 2004; Koottatep et al 2006
Laboratory-scale research on ABR treating toilet wastewater; conducted by AIT in Bangkok (PhD and MSc research), 2002–2008	Wanasen 2003; Khumkhom 2004; Sarathai 2007
Constructed wetlands for Tsunami-hit areas in southern Thailand (project funded by Danida), 2004–2007	WMA 2005; Koottatep and Polprasert 2008
On-site sanitation system for treatment of domestic wastewater on Koh Chang Island; conducted by AIT in collaboration with PCD, 2006	PCD 2006

as the septic tank or the anaerobic filter. The unique design of the ABR makes it possible to separate the hydraulic retention time (HRT) from the solids retention time (SRT) in the reactor, making the ABR a high-rate anaerobic treatment system. Treatment efficiencies of the investigated ABR systems were significantly higher than the ones observed in conventional anaerobic treatment systems. The average removal of organic material (expressed as COD) and suspended solids (SS) in the different laboratory- and pilot-scale ABRs amounted to 72–90% and 78–94%, respectively (Khumkhom 2004; Nguyen et al 2007; Sarathai 2007), which represents a significant increase compared to conventional septic tanks. Hydraulic retention time (HRT, i.e. the average time water remains in the system), wastewater up-flow velocity in the system, the number of up-flow chambers, and peak flow factors (i.e. the ratio between maximum flow rate and average flow rate) were identified as the most significant design factors (Table 2). The system proved to be simple in construction, operation and maintenance, and economically competitive. Construction costs of full-scale ABRs in Vietnam and Thailand amounted to USD 150–270 per cubic metre of reactor, or USD 35–70 per person. The main limitation of the system is its inability to remove nutrients and pathogens to levels complying with Vietnamese and Thai domestic effluent standards, so that a polishing step is required before the treated wastewater can be discharged into the environment.

The constructed wetland (CW) – an efficient polishing system with aesthetic value: Ideally, the polishing process for an anaerobically treated effluent such as an ABR effluent should be aerobic, as oxidative processes complement the reductive anaerobic processes. Linking the two types of processes in this order in a treatment chain is the most efficient way to achieve complete biodegradation of organic material. The CW systems investigated in Vietnam and Thailand (Table 1) produced an effluent with organic material and solids concentrations as low as 15–30 mg/L (BOD) and 13–23 mg/L (SS), respectively (Koottatep et al 2005; Nguyen et al 2007). All wetland systems could meet Vietnamese and Thai national domestic effluent standards in terms of organic load and nutrients. Plant species such as cattails (*Typha angustifolia*) and common reeds (*Phragmites communis*) proved to be suitable as wetland vegetation. Operational problems such as filter bed clogging, plant die-off and odour nuisance were observed in full-scale CWs, mainly due to system overload and inefficient pre-treatment. The studies revealed that a surface area of 2.5–4 m^2 per person is required, at average costs of USD 60–120 per person (land price not included). The main research findings on CWs are summarised in Table 2.

Table 2

Treatment performance, system design, operation and maintenance requirements, construction costs, strengths and limitations of ABR and CW.

	Anaerobic baffled reactor (ABR)	Constructed wetland (CW)
Typical application	– Primary treatment of domestic wastewater at household or neighbourhood level (5–200 people)	– Secondary and tertiary treatment of pre-treated domestic wastewater at neighbourhood level
Treatment performance	– Removal efficiency: COD = 72–90% [a,b,c,i]; SS = 78–94% [a,b,c,i]; TP = 33% [c]; TKN= 47% [c]	– Removal efficiency: COD = 80–90% [a,c]; BOD = 75–85%; SS = 80–95% [a,c]; TN = 40–60% [a,c]
System design, operation and maintenance	– 1 sedimentation chamber, 2–3 up-flow chambers [a,b,c,i] – HRT = 48 hours [a,b,c,i] – Size: 0.3–0.4 m^3 per person – Critical up-flow velocity = 0.5–0.7 m/h [a,b] – Reactor start-up period: 90 days [b] – Critical hydraulic peak flow factor = 4 [b] – De-sludging frequency: 2–3 years [a]	– Series of vertical-flow units, horizontal-flow units, free-water surface units [f]; 2 vertical-flow units in series [a] – HRT = 2–4 days [g,h] – Size: 2.5–4 m^2 per person [h] – Harvesting of wetland plants: 3–4 times per year [h] – Periodic cleansing of CW unit surface [f]
Construction costs	– 150–270 USD/m^3 of wastewater [e,g] – USD 35–70 per person [e,g]	– 400–650 USD/m^3 of wastewater [g,h] – USD 60–120 per person [g,h]
Strengths	– Simple design (no moving parts, no mechanical mixing) – High treatment efficiency (organic material and suspended solids) – High stability under organic and hydraulic shock loads – Low capital and operational costs – Plant operators do not need high-level academic qualifications	– High treatment efficiency (including nutrients and pathogens) – National wastewater discharge standards can be met – Pleasant landscaping possible – Can be cheap in construction if filter material is locally available – Plant operators do not need high-level academic qualifications
Limitations	– Limited nutrient and pathogen removals – Effluent standards cannot be met – Potential production of greenhouse gases (e.g. CH_4) unless treatment or reuse facilities are installed	– High permanent space requirement – Great care required during construction and acclimatisation

COD = chemical oxygen demand; BOD = biochemical oxygen demand; SS = suspended solids; TP = total phosphorus; TN = total nitrogen; TKN = total Kjeldahl nitrogen; HRT = hydraulic retention time.

Sources: [a] = Nguyen et al 2007; [b] = Sarathai 2007; [c] = Koottatep et al 2005; [d] = Khumkhom 2004; [e] = V.A. Nguyen (personal communication, 20 February 2008); [f] = Koottatep and Polprasert 2008; [g] = PCD 2006; [h] = T. Koottatep (personal communication, 9 April 2008); [i] = Wanasen 2003.

22.3.2 Barriers to dissemination of decentralised wastewater management

The expert interviews conducted in Kunming, China, aimed to identify the potential and the limitations of introducing pollution control measures at the source to reduce nutrient discharge to surface water bodies, mainly in the form of decentralised wastewater treatment systems. Two-thirds of the 34 interviewees supported a decentralised approach to pollution control in a general way (Medilanski et al 2007). While the current level of implementation of such at-source measures in the city of Kunming was considered low (85% considered that they are 'not at all', 'very little' or 'little' implemented), 85% of stakeholders anticipated that by 2025, these measures would be 'much' or 'very much' implemented. Despite the high priority given to the implementation of at-source measures for domestic wastewater, the feasibility of such measures is considered 'very low' to 'low' (70%) at the moment. Technical difficulties and a lack of public acceptance were mentioned as main barriers. Perspectives on the situation in 2025 are, however, more promising, with feasibility improving to 85% for domestic wastewater.

Analysis of the interest and the influence of key stakeholders in introducing at-source control measures in Kunming revealed that a small number of key political stakeholders (the Congress, the city government, the Communist Party, environmental protection authorities) are the most important barrier to wide-scale introduction of such measures. A basic initial reluctance of the key political stakeholders to support the introduction of decentralised concepts was observed. It was argued that decentralised sanitation was not prestigious and lucrative enough, that technical options were not yet available, and that the probability of success could not be demonstrated (Medilanski et al 2007).

22.4 Discussion

Decentralised wastewater management represents a valuable alternative to conventional pollution control measures. Anaerobic systems such as the ABR can be considered the core technology in such decentralised concepts, being the first step in the sustainable treatment and reuse of domestic wastewater. The advantage of the ABR compared to conventional septic tanks is its high treatment efficiency in terms of organic matter and solids removal, its stability under hydraulic and organic shocks, and its ability to operate at low liquid but high solid retention times (Koottatep et al 2005; Nguyen et al 2007; Sarathai 2007). ABR effluent still contains high levels of nutrients and pathogens, requiring further treatment in a secondary and tertiary treatment process. Koottatep et al (2005), the Thai Pollution Control Department (PCD 2006) and Nguyen et al (2007) demonstrated that CW systems are well suited as a post-treatment step. Constructed wetlands not only provide advanced treatment at reasonable costs; if well designed and operated, they also have an aesthetic value. The CW system implemented on Phi Phi Island (a Tsunami-affected tourist island of Krabi Province, Thailand; Figure 2), which treats 400 m^3 of wastewater per day, was well accepted and is frequently visited by authorities, scientists and tourists. By producing a source of irrigation water for nearby green areas, the treatment system helps to mitigate the acute water scarcity on the island. A treatment chain combining ABR and CW provides a technically and economically sound system for the treatment of domestic wastewater, and makes it possible to close the water and nutrient cycles by reusing treated wastewater in irrigation.

The expert interviews conducted in Kunming, China, indicate that decentralised approaches to pollution control are not yet perceived as an option that can be implemented on a wide scale. Interviews with key representatives of the Vietnamese Environmental Protection Agency (T.H. Ha, personal communication, 1 December 2004) and the Ministry of Communication, Transportation, Post and Construction in Lao PDR (K. Thaiphachanh, personal communication, 5 January 2007) confirmed this perception in other countries of Southeast Asia. According to Parkinson and Tayler (2003) constraints on wide acceptance and application of pollution control measures at the source may relate to inappropriate institutional and legislative frameworks, a lack of managerial capacity and availability of technical skills, and

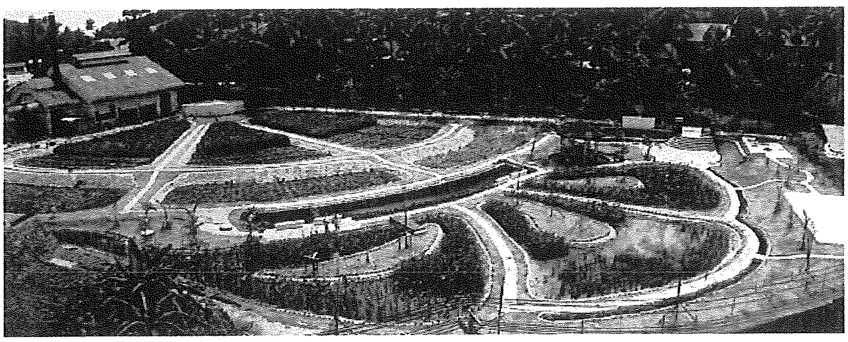

Fig. 2 Constructed wetland system treating domestic wastewater of hotels and households on Phi Phi Island, Krabi Province, Thailand. (Photo by Thammarat Koottatep, 2007)

a lack of knowledge about and trust in technical innovations. These constraints, as well as possible measures for overcoming them, are further discussed below.

Social and political challenges: Overall, a lack of government commitment to address wastewater-related problems has led to a political and institutional environment that offers few incentives to manage wastewater effectively. The main challenge is to create informed demand for improved wastewater management systems. Advocacy at the political level is required, and at the community level there is a need for campaigns to promote the benefits of improved wastewater management. The Household Centred Environmental Sanitation (HCES) planning approach described by Eawag and the Water Supply and Sanitation Collaborative Council (Eawag and WSSCC 2005) provides a suitable framework for this purpose. The positive examples in Vietnam (Beauséjour and Nguyen 2007), China (Chuan et al 2005) and Thailand (Koottatep et al 2007), where decentralised wastewater treatment systems have been introduced in demonstration projects, indicate the important role of such projects in stimulating wider interest in the benefits of such approaches. The park-like CW system implemented in the tourist area of Phi Phi Island, Thailand (Figure 2), is frequently visited, which is evidence of its acknowledgement and reputation.

Institutional and legislative challenges: In 1997, 77% of the countries in Asia and the Pacific indicated a need to define formal wastewater management policies and enact further supporting legislation to improve enforcement (UNESCAP 1997). Performance incentives are still weak (Strauss and Montangero 2003). Official design standards are generally not framed in a way that supports the application of innovative systems such as the ABR or the CW discussed above. In China, for example, there is little legislative support for practical trials and implementation of innovative urban wastewater management systems (Medilanski et al 2007). There is a need to develop appropriate standards to be utilised for the design and construction of decentralised wastewater systems. The introduction of the ABR technology in national urban infrastructure standards of Vietnam is believed to be an important step towards its wider implementation in the country (MOC, in preparation).

Limited capacities to plan, implement and operate decentralised systems: The successful adoption of at-source pollution control measures is limited by the need to ensure that the operation and maintenance of the chosen technologies are compatible with the levels of knowledge and skills available at the local level (Parkinson and Tayler 2003). There is often a lack of knowledge about decentralised options as well as shortages in the qualified work force and the skills needed for operation and maintenance. Environmental protection agencies in Vietnam, Laos and Thailand expressed the need to disseminate technical information in appropriate forms and languages in a way that is understandable to those who are responsible for the design and operation of decentralised wastewater management systems (T.H. Ha, personal communication, 1 December 2004; K. Thaiphachanh, personal communication, 5 January 2007). In addition, most authorities express a need for training local stakeholders to enable them to understand how technologies work and what their operational and maintenance requirements are. Technical guidelines in local languages, such as those developed by Nguyen (2007) and EEM/AIT (2004) on septic tanks, ABRs or CWs in the framework of the NCCR North-South programme, facilitate transfer of knowledge from the research community to local practitioners.

22.5 Conclusion

In rapidly growing cities of Southeast Asia, decentralised technologies for wastewater treatment have a great potential for mitigating the problems of water pollution and water scarcity. We were able to demonstrate that appropriate technologies for the decentralised treatment of wastewater exist. The investigated treatment systems (ABR, CW) can be applied at household and community levels alike, and produce an effluent that allows the safe reuse of treated wastewater for irrigation. However, such treatment systems have not been widely utilised and remain restricted to localised areas and pilot projects. The fact that most experts and local authorities interviewed consider today's decentralised solutions as technically inadequate and not feasible in Southeast Asia is an indication of the ineffective transfer of knowledge from research institutions to decision-makers and practitioners. In order to overcome the barriers to widespread recognition and implementation, capacity building is required at the four levels associated with advocacy and awareness raising, development of appropriate policies, institutional reform and strengthening, and technical and managerial training. Questions arising include the role that development agencies and research institutions should and can play in building up these capacities and promoting decentralised wastewater management. Studies are needed to identify the most appropriate partnerships between central and local governmental agencies, the private sector and the communities in decentralised wastewater management schemes, taking into account the socio-economic and environmental heterogeneity of Southeast Asian countries.

Endnotes

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