Understanding sanitation options in challenging environments

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Across South-east Asia many of the poorest communities live on marginal land or over water. Owing to adverse geographic and climatic conditions in these areas, neither conventional nor most well known 'alternative' sanitation options are feasible at affordable prices for poor communities or poor governments. A recent study in the region has started to develop a typology of challenging environments for sanitation as a means to: assess the scale of the challenges; understand the specific issues involved in improving sanitation; identify, develop or improve sanitation technologies to cope with different environments; and to disseminate the results in the study countries, regionally and beyond.

Keywords: low-cost sanitation, flood-prone, high groundwater, coastal, riverbanks, Indonesia

East Asian leaders recognize the need to move beyond MDG targets towards universal access to basic sanitation

In 2002 world leaders committed themselves to the Millennium Development Goals (MDG) for sanitation by halving the number of households without basic sanitation facilities by 2015. By doing so, they motivated countries and development organizations to improve their focus on increasing access to basic sanitation. At the East Asian Ministerial Sanitation conference (EASAN) in December 2007 East Asian leaders discussed the need for moving beyond the MDG targets towards universal access to basic sanitation for all citizens.

Across East Asia and elsewhere, many of the poorest communities live on marginal land, or over water. In rural areas this could be traditional land; or communities may have settled or been resettled on land unusable for other productive purposes. In urban areas, land is more costly, but the demand for low-cost service labour and many opportunities for informal employment and income drive urban migration from marginal rural livelihoods. The result has been sprawling urban slums often situated on land not suitable for habitation. Urban planning and land use mechanisms are not consistently enforced or effective, and the political pressure to allow housing for

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lower income households may be greater than the consequences of burgeoning slums. Climate change will increase migration pressure in urban areas, raise sea levels and increase flooding due to extreme weather patterns.

In 2005 UN HABITAT estimated the slums of East Asia to be home to more than 210 million people in 2005 or 21 per cent of the population. As a consequence, in and around many thriving towns and cities and in rural areas of East Asia, poor communities are living in areas where neither conventional nor the better-known 'alternative' sanitation options are feasible at affordable prices for poor communities or local governments. Primarily this is due to the lack of solid, dry ground for the construction of latrines with pits or septic tanks, or for laying sewers and drainage. In other areas where pits, pipes and tanks are feasible, seasonal or periodic flooding undermines both the super-structure and sub-structure and results in extensive pollution and wasted capital investments.

Poor communities live in areas where neither conventional nor 'alternative' sanitation options are feasible

Improved urban planning and housing development programmes are beginning to include infrastructure considerations when approving new areas for legal settlement. Likewise, some locations are being designated unsuitable for housing development because of public health risks and the high cost of developing adequate infrastructure. While these legal and planning measures for new developments are being institutionalized, well-established slum and low income housing settlements may be legalized, despite their location and the unsuitable ground conditions. These areas are a priority for sanitation infrastructure development, as they are likely to be permanently settled.

Study outline

Challenging environments are found in Indonesia, Philippines, Lao PDR, Cambodia and Vietnam and in the neighbouring countries of Thailand, Timor-Leste and Malaysia. For example: in Indonesia and Philippines there are many communities built on coastal land, in swamps and over estuaries and rivers; Vietnam and Indonesia have many communities living in seasonal and tidally flooded areas; and Vietnam, Cambodia and Lao PDR have riverine or floating communities which live on their boats throughout the year.

WSP in East Asia is undertaking a regional research study on sanitation in challenging environments

The Water and Sanitation Program (WSP) in East Asia is undertaking a regional research study on sanitation in challenging environments. The study has been completed in Indonesia, and is under way in Lao PDR and Cambodia. The study seeks to better understand the scale and nature of the challenges in each country prior to identifying options or mitigation measures, then disseminate the findings as a guidance note. The study in each country starts with a situation analysis that includes:

- identification and categorization of the types of challenging environment based on common geographical features and the indicative number of people affected by each type of challenging environment;
- key social, health and other impacts of the lack of adequate sanitation for each type of environment, the common coping mechanisms, attitudes and priorities;
- identification of existing sanitation facilities and behaviours in each type of challenging environment; leading to
- identification of the main types and key characteristics of challenging areas, and the priority areas for development of solutions.

The study seeks to understand the scale and nature of the challenges and identify mitigation measures

The findings of the situation analysis are being used to design a second phase focusing on appropriate solutions, which include further field studies, design development or pilot implementation.

Phase one includes a desk study, interviews and stakeholder consultation workshops and field visits. The field visits include meetings with local government and community leaders, community focus group discussions, transect walks, observations and household interviews.

By undertaking the study regionally, findings and solutions can be shared between countries for local adaptation, thus reducing the risk of 'reinventing the wheel' or making similar mistakes in designs.

Challenging environments in Indonesia

The situation analysis identified four main types of challenging area, each with broadly similar physical characteristics, which have an impact on technical solutions. These four types of area contain the majority of communities who are unable to build conventional or alternative sanitation solutions, and include communities living:

- along riverbanks and above rivers (2+ million people);
- along and above coastlines and estuaries (1.5–2 million);
- in swamp areas or with high groundwater levels (1.5–2 million); and
- in areas which flood on a predictable and seasonal basis (3+ million).

While the challenges appear to be technical, the social challenges are equally substantial

Other communities live around lakes and in dry rocky areas – but the number of people affected is considerably lower and thus they were not included in the study.

Housing in a swamp area of Palembang, Sumatra

Until there was a convenient supply of affordable clean water, improved sanitation was of little interest

Technical and social challenges

While the challenges appear at first sight to be technical (e.g. tidal forces resulting in erosion, corrosive saline environments, unstable soils, unpredictable flooding, etc.), the study found that the institutional, social and economic circumstances of the communities meant that social challenges were equally substantial. For example, in most of the communities studied there was no shortage of water *per se*, but

Bathing and washing activities

the water available was highly polluted. While pollution did not stop the water being used in many ways (washing clothes, bathing, etc.), until a convenient supply of affordable clean water was made available for domestic use, improved sanitation was of little or no interest. In all the communities children were swimming and playing in polluted water.

Generally, communities which had ready access to clean water were more interested in latrines and improving their sanitation facilities. The use of a convenient latrine with privacy and a water supply for anal cleansing (a cultural requirement) was the highest priority, with the substructure poorly understood and the means of excreta disposal and storage of little or no interest. In many cases the communities believed that their current defecation practices have no negative impact. This lack of understanding of environmental health considerations and justification for current practices has also been identified in other sanitation studies (Nielsen, 2007), which indicate that some rural dwellers believe disposing of excreta into the river is a positive action as it feeds the fish and avoids polluting the village well water.

Some believe disposing of excreta into the river is positive as it feeds the fish

The following summarizes specific findings for the main types of challenging area in Indonesia.

Riverbank communities

The number of settlements along riverbanks has grown as the demand for housing increases in high-density cities. The settlements are usually occupied by migrants and other lower income households who cannot afford the high rents and land prices in more desirable areas. Illegal or semi-legal occupation along the riverbanks or above rivers is common.

For example, in North Jakarta alone, more than 150,000 people live in squatter areas along riverbanks and toll roads. Recent research by Mercy Corps Indonesia (2008a) indicates that most of Jakarta's 230,000 squatters lived in slums on flood-affected riverbanks. In cities such as Banjarmasin and Palembang, well-established communities also use the rivers for transport, access and as the source of their livelihoods.

Most of Jakarta's 230,000 squatters lived in slums on flood-affected riverbanks

The housing over the river tends to be simple, made of temporary or semi-temporary materials. River water is used for most basic needs such as cooking, washing, bathing and cleaning teeth, although drinking water is also purchased by many households. Water for use inside the house may be pumped up from the river via plastic pipes. The river also receives all domestic wastewater; most households practise open defecation or fixed point open defecation in overhung or floating toilets that discharge directly to the river.

Refuse on the riverbank of Musi River in Palembang

The river and riverbank housing is usually dense with no clear settlement pattern. Access roads vary, but most are not large enough for four-wheeled vehicles. In most areas, there are no basic services such as water supply, sewerage or solid waste collection and management. The lack of solid waste (refuse) collection has a major environmental impact with refuse being dumped in open spaces, rivers, drains, under houses and in the streets.

The key technical sanitation challenges are as follows:

- lack of land for construction of latrines due to densely populated housing;
- limited access between houses often only through narrow lanes;
- seasonal elevations in the river water level;
- land around the riverbanks may be waterlogged or unstable; and
- domestic wastewater and solid waste pollutes the river water, which is used for domestic uses: bathing, cooking, cleaning, cleaning teeth, etc.

Many communities are illegal, affecting the willingness of households and local government to invest in sanitation

The institutional, social and economic challenges are listed below:

- Many communities are illegal or semi-legal, despite often being long established and unlikely to be moved. This may negatively impact the willingness of both the household and local government to invest in sanitation improvements.
- Access to clean water for drinking and other domestic uses is a priority.

Existing communal latrines built by government are often not used or maintained

- Most poor households focus on providing for their basic needs, do not pay for latrine use and are not willing to pay as they do not perceive any negative impact of their current practices.
- Existing communal latrines built by government are often not used or maintained.

Coastal areas and estuaries

Indonesia's 81,000 km of coastline is a source of livelihood to around 140 million people or 60 per cent of the country's total population. Eighty per cent of these coastal dwellers, known in Indonesian as *masyarakat pesisir*, are poor, marginalized and have a low level of education (Marine and Fishery Department, 2008). Most are fishermen, or work in the informal sector as dock workers, factory workers or building site labourers.

Settlements in coastal areas and along estuaries are typically built above the high tide level by being elevated on concrete or wooden piles. In the larger cities the coastal settlements have grown into dense housing areas and may extend hundreds of metres out to sea. Houses are often separated by small footpaths a metre or two wide with the larger neighbourhood roads only slightly wider and constructed with concrete or wood.

Most people who live above or near a water body defecate directly into the water

Most people who live above or near a water body defecate directly into the water, or into a plastic bag and dispose of it either in the water or on land. Notably, no open defecation was observed in some places (e.g. Baru Tengah Village, Balikpapan) as most residents practise fixed point defecation inside their houses, disposing of excreta directly into the water through a hole or a pipe.

Although solid waste systems exist in some urban coastal areas, they are not necessarily used. People continue to dispose of solid waste in the sea, in the belief that it will be washed away and not pollute the environment, despite evidence to the contrary. Disposing of garbage under the house is a common practice and, as a result, the immediate environment is clogged with solid waste, including plastic bags containing excreta.

Poor sanitation practices in coastal areas cause environmental degradation, but people do not use the sea for drinking

While the poor sanitation practices in these areas cause severe environmental degradation, unlike river communities, people living in coastal areas do not use the sea or estuary water for drinking, cooking and other purposes because of its high salinity. Therefore, access to a source of fresh water is a priority for the household. Typically households depend on water from deep wells with privately owned piped systems, water vendors bringing water from the city or, in a few cases, piped water supplied by the local water utility. Where there is no access to improved water sources, households may still rely on saline shallow wells or rainwater for domestic uses.

In some cities, such as Jakarta and Semarang, houses that are now on the coastline were originally constructed inland. Due to a high level of subsidence, caused by groundwater abstraction, rising sea levels and increased flooding, the ground level together with the houses is subsiding by 7–20 cm a year (German-Indonesia Technical Cooperation, 2008). Households who can afford it, have added another storey to their houses. Those who do not have the resources are living partially under water, with furniture and other possessions raised on bricks.

The key technical sanitation challenges are as follows:

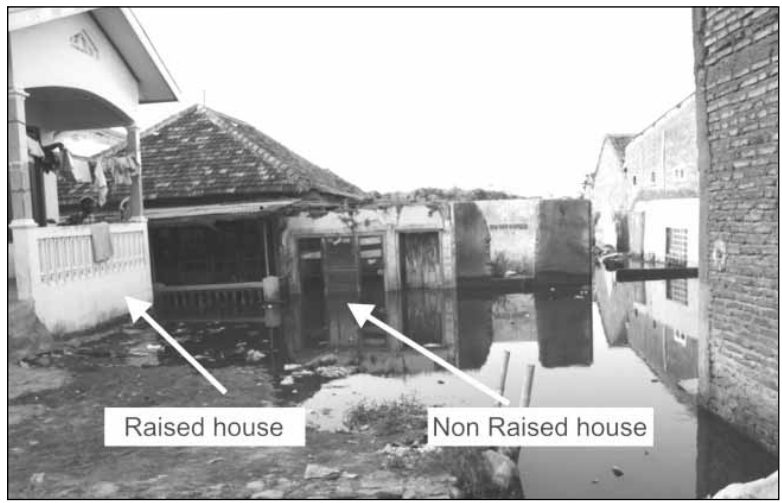
There is a lack of land for constructing latrines due to densely packed housing along the coastline

- a lack of land for construction of latrines due to densely populated housing along coastline and extending hundreds of metres over the sea;
- limited access between the houses, often through narrow lanes;
- the corrosiveness of saline water, diurnal tidal forces that result in erosion, and both high and low tide levels; and
- ongoing rates of land subsidence.

The institutional, social and economic challenges include the following:

People have a strong preference for household latrines, over communal sanitation

- many communities are illegal or semi-legal, despite being well established and unlikely to be moved in the near future;
- the households need to prioritize access to clean water ahead of sanitation;
- people have a strong preference for household latrines, over communal sanitation options;
- raising community awareness of environmental sanitation to increase willingness to pay for sanitation systems.



Raised and non-raised houses in a coastal area of Semarang

Swamps and high groundwater areas

In the late 1980s, the government implemented an enforced transmigration programme to reduce overcrowding in Java. Millions of hectares of swamp were cleared for development in Sumatra, Kalimantan, Sulawesi and Papua to accommodate migrants from Java. Also, between 1996 and 2000, the One Million Hectare Peatland Program saw thousands more hectares of peatland cleared for settlement. Although these programmes have been discontinued, many settlements developed under them still exist today.

Swamps are flat areas that are continuously or seasonally inundated as the result of poor or obstructed natural drainage. Swamps can be either tidal near coastal areas, estuaries and other areas affected by the tide, or non-tidal inland swamps in flat areas near to lakes, rivers or other areas with no rainwater runoff.

Palembang is a city developed in a tidal swamp by the Musi River in Sumatra, where 25 per cent of the total population of 1.4 million lives in tidal swamp and river areas. Typically population density is low. In Palembang, most houses in swampy areas are made of wood and elevated 1–1.5 m above the ground. The wooden neighbourhood roads are also elevated to this height.

Where there are irrigation ditches, people may build a private toilets over them

Toilets in these areas are a typically simple, wooden and/or plastic construction, usually located away from the house and may be shared by more than one household. Inside, there is a defecation hole with footrests on either side and excreta drops straight into the water below, or is collected in a used metal drum. Where there are irrigation ditches, people may build private toilets over them, in the

Road in a swamp area of Palembang

belief that this is better practice because the excreta is washed away by the water flowing along the ditch. Floods, however, can render these toilets unusable.

Open defecation and no clean water for handwashing is not considered a problem

The low level of education in these communities influences attitudes and practices. Open defecation and an absence of clean water for washing after defecating is not considered as a problem. Due to the difficult natural conditions, especially during the rainy season, people living in these areas are more concerned about their economic survival, flooding, road access and sources of drinking water than they are about sanitation.

High groundwater areas are those with groundwater within 1 metre of the surface either seasonally or permanently. Banda Aceh is an example of a city where most of the population, rich and poor alike, is affected by high groundwater levels.

The key technical sanitation challenges are listed below:

- In swamps the groundwater table varies, but is generally high, which means that soil permeability is low.
- The local water systems are fragile in peatland areas and changes in land use, no matter how small, have a dramatic effect on the groundwater table.
- Road access can be extremely difficult, especially during the rainy season.

The institutional, social and economic challenges include the following:

- The priority of the communities is to deal with the challenge of living with poor access, flooding and limited economic possibilities.
- In areas where the swamp or groundwater is saline or highly polluted, a priority is put on access to drinking water ahead of sanitation.

Areas prone to regular flooding

Rapid urban development increases the risk of flooding as the rainwater infiltration rate decreases

Rapid population growth has resulted in agricultural and forest land being developed for settlements and urban development. This rapid urban development has had many environmental impacts, including an increased risk of flooding as the rainwater infiltration rate decreases. This is worse in flat areas where adequate drainage slopes to release runoff cannot be constructed. As a result of uncontrolled urban development and the impacts of climate change, flooding is now commonplace in many Indonesian cities. The implications for environmental sanitation are significant. Untreated excreta are carried by the floodwaters from substandard septic tanks and from direct

defecation into rivers, which contaminates water sources, while flood victims are exposed to untreated sewage.

When untreated excreta contaminates water sources, flood victims are exposed to sewage

An inventory of rivers found that 1.4 million acres (567,000 ha) of land throughout Indonesia is flood prone and that 600 of Indonesia's 5,590 rivers are a potential flood risk (Ministry of Environment, 2006). According to the National Disaster Management Agency, 27 of Indonesia's 33 provinces are at risk of flooding or landslides and in 2008 floods and landslides occurred in all 27.

Floods happen in urban and rural areas, well-planned and unplanned areas, and can affect the rich and poor alike. The affected houses may be permanent, semi-permanent or temporary structures, with well-treated or untreated wastewater and off-site or on-site sanitation. Because of this broad variation, sanitation management in flood-prone areas needs to be addressed case by case. In Jambi, the municipality's Sanitation Situation Analysis identified 21 flood-risk points, including risks of flood from Batanghari River and risk points from high rainfall. These flood-risk areas are home to about 30,400 people in the city.

The people most vulnerable to flooding were poor people who live in riverbank or coastal slums

A study by Mercy Corps (2008b) found that flooding in 2007 affected a much larger area of Jakarta than in previous years. Floods in 2002, for example, affected around 45 km^2, compared with 183 km^2 in 2007, affecting around 305,000 people. The people most vulnerable to flooding were poor people who live in riverbank or coastal slums. The most flood-prone areas in Jakarta are 41 neighbourhoods in North Jakarta and Central Jakarta, covering a total area of 38 km^2.

In Jakarta, a survey of 2,880 low-income earners carried out during the preparation of a 2005 Master Plan for Domestic Waste Management (Miller, 2006) found that 62 per cent of respondents had septic tanks less than 10 metres from water sources; 71 per cent used groundwater for all purposes; 45 per cent did not have their own toilet; and only 13 per cent said they understood how wastewater causes pollution. Open defecation directly into the water is common practice and most private toilets discharge directly into the water body.

Owing to the diversity of flood-prone areas, it is difficult to make specific conclusions about sanitation practices. Some people said they had no difficulties urinating or defecating during floods. If a private toilet is not available, they use the public toilets that have been built in anticipation of flooding. Many even felt that the best time to defecate was when the floodwaters were high.

The women's group realized the importance of sanitation, but financing the facilities was a major obstacle

The men in focus group discussions in the Tanjung Mas area of Semarang did not seem to be aware of the close link between diarrhoea and the sanitation conditions in their living environment and they saw no reason to separate excreta from the environment (by means of a septic tank or other treatment). Most felt comfortable disposing of excreta in the local environment. The women's group, by

Public toilet

contrast, realized the importance of proper sanitation facilities and practices, but felt that financing these facilities was a major obstacle.

The key technical sanitation challenges are:

- little available land in high-density, poor neighbourhoods which even when they are not flooded may not have access to adequate sanitation;
- flood levels vary from year to year;
- during floods, waste from rivers and substandard septic tanks flows around the communities, into water sources and results in extensive human contact; and
- flooding is unpredictable, but tends to be more frequent than in the past because of rapid urbanization.

The institutional, social and economic challenges include the following:

Flooding is exacerbated by the poor management of solid waste

- Community attitudes and practices are very varied.
- During times of flood household priorities are on survival and salvaging household goods.
- Flooding is exacerbated by the poor management of solid waste.

Review of sanitation options piloted in Indonesia

During stakeholder consultations it emerged that there has been considerable work done by research organizations and NGOs in developing sanitation options for the specific challenging situations found in

Considerable work has been done to develop sanitation options for challenging situations

Indonesia. Information about these options, however, has not been effectively disseminated, pilots have not been replicated, nor was there a programme of monitoring or any information available about how the pilot systems were functioning several years after they were installed. This resulted in the second study phase – a field review and assessment of the existing options leading to recommendations and if necessary, any adaptations or improvements required.

The second phase involved discussions with the system developer or manufacturer; stakeholder consultations on the methodology, options and study locations; field visits to ten sites including meetings with local government, community users and operators; and analysis of data followed by final consultations with stakeholders. The assessment looked broadly at the criteria shown in Table 1 as factors contributing to sustainability and affordability.

Description of options and findings

Table 2 gives a summary of the existing sanitation options reviewed. The decentralized treatment systems were found to be adaptations of known technologies, which had been specifically redesigned to cope with the challenging conditions. No internationally produced standard plants were considered.

The field survey, while intending to assess the performance of wastewater treatment, was unable to take effluent samples from most of the systems as effluent outlets were under water or underground.

Information about the detailed designs and the analysis of each system is available from WSP. The common technical findings are listed below:

None of the systems reviewed had been desludged, and some didn't have manholes for desludging

Sewage treatment systems built in the coastal or river water were harder and more expensive to construct

- *Basic maintenance had not been carried out*. Where various filters or grease traps were used, they had not been cleaned or backwashed. None of the systems reviewed had been desludged (see finding below regarding access), and some did not have manholes for desludging.
- *The sewers above the water level were not firmly attached to concrete piles*. As they were exposed, they were more vulnerable to accidental breakages and increased wear and tear than buried sewers. However identification of leaks, routine maintenance and repairs was easier.
- *Sewage treatment systems built in the coastal or river water were harder and more expensive to construct*, and more vulnerable to tidal erosion, and damage at high tide or during floods. Access for desludging was more difficult or even impossible.
- *Plastic and fibreglass, although effectively watertight, floats upwards and moves*. None of the 'floating' systems was assessed as

Table 1. Criteria for assessment of existing sanitation options

Criteria	*Assessment*	*Impacts*
Technical aspects		
Cost of construction	Construction costs include consultant and supervision costs, community planning and participation. The budget may come from households, community, local or central government, NGOs or other partners.	Affordability Coverage
Ease of construction	Community members, local artisans or local government will be more able and likely to construct and maintain a simpler design, which is also likely to cost less.	Sustainability Affordability
Suitability for the environment	Suitability is the compatibility of the design and construction with the environmental challenges. The option is suitable if it is able to sustainably ensure safe separation of excreta from humans under the prevailing conditions, e.g. anticipates the highest and lowest tides, flood conditions, etc.	Sustainability
Performance	Performance determines the effectiveness in treating the incoming wastewater to reduce environmental impact.	Environment
Durability	Durability is the ability of the design and construction to withstand the various forces acting on it (community use, seawater corrosion, tides, flood water, etc.) over its design life. More durable structures may cost more.	Sustainability Affordability
Replicability	The ability of the community, local or central government to replicate the system, based on ease and cost of construction, availability of suitable materials and technical expertise, ease of operations and maintenance, etc.	Coverage and scaling up
Desludging access and period	Local government, private sector or the community need to be able to desludge the treatment system and safely dispose of the sludge at an affordable price. Access for vehicles or manual equipment is required.	Critical for sustainability
Ease of operation and maintenance	A system which is inexpensive and simple to operate and maintain is more likely to be well maintained and operated by the community, or other stakeholders such as local government.	Sustainability Affordability
Availability of spare parts	The availability of spare parts on the local market is critical in ensuring the sustainability of the system. This may be a deciding factor in selecting a system.	Critical for sustainability
Non-technical aspects		
Acceptability, willingness to pay	The system must be acceptable to the community and result in a willingness to pay for installation, connection or other use of the system and payment of the user fees or tariffs.	Critical for sustainability
Management system	To ensure sustainability an effective management system is required to ensure that collection of tariffs (user fees), caretaker supervision, operation and maintenance, repairs, and desludging are carried out.	Sustainability
Operation and maintenance cost	The recurring cost required to operate and maintain the system, including payment of caretakers, desludging and repairs. A lower operations and maintenance cost will reduce user fees and make the system more affordable.	Affordability
Local government role in desludging	Local government needs to ensure that desludging services are available and the sludge is disposed of safely (e.g. sludge treatment plant). The desludging service (tankers) could be operated by government or private sector.	Sustainability Environment
Local government monitoring	Local government should regularly monitor the facilities to ensure they are operating correctly, evaluate the advantages and disadvantages of the system and provide support if needed. Regular monitoring will support sustainability of the system and inform future development.	Sustainability

Table 2. Summary of existing sanitation options reviewed

Challenging environment	*Wastewater treatment*	*Connection and toilet and no. of households (HH)*	*City*
Coastline and estuaries	Baffled reactor → discharged	Simplified sewer – house connection to manual water flush (50 HH)	Klandasan Ulu, Balikpapan
	Septic tank → gravel filtration → discharged	Simplified sewer – house connection to water flush (10 HH)	Makassar Timur, Ternate
	Baffled reactor → discharged + biogas digester	Communal bathing, washing and toilet block	Mandaranrejo and Panggung, Pasuruan
	Aerobic treatment: pre-treatment → aeration → equalization → coagulation → sedimentation → discharged + sludge treatment and disposal unit	Sewerage system – house connection to water flush (1,080 HH)	Margasari, Balikpapan
Rivers and riverbanks	Baffled reactor → upflow filter → discharged	Communal bathing, washing and toilet block	Bagan Deli, Medan
	Baffled reactor → upflow Filter → discharged	Simplified sewer – house connection to water flush (70 HH)	Darakan Barat, Yogyakarta
	Baffled reactor → rotating biological contactor → discharged + simple sludge treatment	Simplified sewer – house connection to water flush (45 HH)	Kricak Kidul, Yogyakarta
	Tripikon-S (three concentric PVC pipes) → discharged	Communal toilet	Prawirodirjan, Yogyakarta
	Floating fibre glass septic tank (sedimentation → upflow filter → discharged)	Individual household toilet	Pangembangan, Banjarmasin
Swamp and high groundwater	Individual septic tanks → sealed wetland → discharged (small bore sewer)	Small bore sewers from household septic tank and water flush toilet (18 HH)	Lam Kruet, Aceh Besar
	Concrete ring septic tank → concrete ring upflow filter → discharged	Communal toilet (14 HH)	Mun Bungo, Aceh Besar
	Individual septic tank → wetland system or biofiltration → wetland system	Individual household toilet	Keude Aron and Kahju, Aceh Besar
	Fabricated individual reinforced concrete ring septic tank → wetland system	Individual household toilet	Kampung Pande and Baet, Aceh Besar
	Biofiltration → discharged. Biofiltration using prefabricated fibreglass system (Biofil, Biotek, Biority, etc.)	Individual household toilet	Krueng Raya and Ulee Leu, Aceh Besar
	Baffled reactor → discharged	Communal bathing, washing and toilet block	Kelayan Tengah and Teluk Dalam, Banjarmasin
	Baffled reactor → discharged	Communal bathing, washing and toilet block	Yong Panah Hijau, Medan
Flood-prone areas	Baffled reactor → discharged through check valve	Simplified sewer – house connection to water flush toilet (105 HH)	Bakalan, Pasuruan

sustainable unless firmly anchored, and therefore not floating. Any movements combined with the weight of the system put continual forces on the joints and seals which cannot be sustained in the long term.

- *Access for desludging equipment was not generally well planned and designed* and many systems could not be evacuated or manually dug out and the contents removed.
- *Detailed design and quality of construction was often sub-optimal* with incorrect details making a difference to sustainability, operation and maintenance (e.g. position of outlet, type of connection used, position of manholes, attachments to piles, etc.).

The key technical recommendations are as follows:

- *The construction cost of between US$150 and $1,200 per household is higher than the communities are willing or able to pay*. The high costs are mainly due to the inclusion of tertiary treatment because the effluent usually cannot be disposed of into soakaways or infiltration trenches. The need for more durable and completely watertight structures adds further to the construction costs. Even if the existing designs were reviewed and reduced in cost, it is unlikely that they would be affordable, given the evident low incomes and willingness to pay of the communities.

Operation and maintenance in challenging environments is more difficult

- *The operations and maintenance in challenging environments is more difficult* and an effective management system is critical. The systems require a more frequent maintenance schedule than in average conditions: for example, broken sewers will leak directly into the water rather than be absorbed by the ground, and therefore need immediate identification and repair.
- *All community managed systems need a technical back-up or referral service*, to provide technical advice and support when major repairs are required. Community understanding, demand and ownership of the system is critical. Without willingness to pay user charges to cover operations costs, sustainability is unlikely.
- *Desludging at 3–5-year intervals needs to be planned* (manholes, access and suitable vehicles/transport) at the time of design and construction. The community needs to be a party to the plan and know how and where the sludge will be removed and disposed.
- *Where feasible, sewage treatment systems are easier and cheaper to construct and maintain if built on land* to reduce damage from tidal erosion, high tides and flooding. This may also make desludging access easier. For community managed systems the use of mechanical equipment should be avoided, because of the high running costs and more complex maintenance requirements.

- *Solid waste management improvements are needed alongside wastewater treatment* if the environmental sanitation conditions of the communities are to be substantially improved.

Non-technical recommendations are as follows:

No options are sustainable without community ownership

- The construction of technically feasible solutions is possible, but there are *no options that are sustainable without community ownership, effective management systems and quality operations and maintenance*.
- *The communal DEWATS systems with decentralized treatment* – both communal toilets and simplified sewerage with house connections – are most feasible for financial subsidies by local or central government or NGOs. Some of the systems reviewed are in the same cost range as those funded by the Government of Indonesia under its national sanitation by communities program (~$300/household) and are therefore judged as 'affordable' for co-funding between local and central government together with the households or community.
- Owing to the higher cost of providing adequate treatment, *communal sanitation systems in challenging environments would be an appropriate target area for government sanitation subsidies* as they would also (aside from some flood-prone areas) be targeting poorer households. This would also comply with Indonesian Government regulation which allows subsidies to communal and decentralized sanitation systems.

Affordable sanitation construction of individual systems by the household is difficult

- *Affordable sanitation construction of individual systems by the household is difficult*. A subsidy for the substructure (sewage treatment) could be considered by development agencies and NGOs, but Indonesian regulations do not currently permit subsidy by government of individual systems.
- The *operation and maintenance costs could be affordable if community demand for improved sanitation is raised*: for example, if a safe and convenient water supply is available, and sanitation developments have involved the community then willingness to pay has been demonstrated to be higher. Effective treatment, a long design life and high usage would increase the affordability of operation and maintenance per household.

Box 1. Applying study results elsewhere

Although originally planned to take place in parallel, the Indonesia assessment produced results before the work in Cambodia and Laos which allowed consideration of how the findings could be applied in other countries. Some of the physical conditions found in Indonesia are also found in Cambodia, while others were less relevant. The three most important challenging environments in Cambodia are areas:

- which are seasonally flooded, especially along the Mekong river and the Tonle Sap;
- with seasonally high ground water levels; and
- where communities are living on the water (in boats or 'floating houses').

Addressing sanitation is generally a low priority for families, and in many areas the non-availability of waste disposal options is not seen as a problem. Rural areas are generally not densely populated, and finding spaces close to the household for open defecation is rarely a problem. Likewise, in floating communities, disposing of waste on one side of the floating dwelling, while taking water for domestic use from the other side is regarded as acceptable and without negative implications for health or wellbeing. Water quality measurements confirm that this is not as irrational as it may seem. *E. coli* counts on the side where waste is disposed of reach 7,000/100ml, while the side where water is collected, the highest measurement was 200 /100 ml.

With low awareness, low incomes, few available options and a general disinterest in the details of waste disposal i.e. the choices for below ground components, addressing sanitation in challenging environments is even harder than tackling rural sanitation in general.

At this point, the Indonesia study findings prove useful to Cambodia. Although some sanitation development work is going on in floating communities, little has been done to develop, pilot and evaluate sanitation technologies for use in challenging circumstances. The Indonesia study uncovered an unexpectedly large number of local options and pilots. While some of these require further evaluation and development, and some may be too expensive for income levels in Cambodia, the findings present a starting point for authorities and agencies in Cambodia as they struggle with the question of solving this sanitation challenge.

Further evaluation and development of the available technologies should not be limited to Indonesia. Carrying out a regional follow up phase could directly benefit and 'kick-start' solutions in Cambodia, while at the same time demonstrating the robustness of the final options.

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