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Guidance note for National Programme Managers and Engineers

OPTIONS FOR SIMPLE ON-FARM WATER TREATMENT IN DEVELOPING COUNTRIES

INTRODUCTION

The lack of wastewater treatment capacity, which is especially prominent in low-income countries, has resulted in untreated wastewater polluting streams and rivers used for crop irrigation. This situation calls for further options for health risk reduction. Hence, while source treatment of wastewater remains the priority option, implementing supplementary, or in the worst case alternative, non-conventional treatment or non-treatment measures appears, at least for the time being, crucial to reduce health risks posed by the use of untreated or only partially treated wastewater in agriculture.

This Guidance note presents some point-of-use irrigation water treatment options, which are low-cost, often build on farmers' own infrastructure and have shown potential in reducing microbiological crop contamination in smallholder farming (0.05-0.8 ha) in developing countries. The effectiveness of most systems varies with the area available and commitment of farmers to install and/or maintain them. While the area can not be changed, farmers' commitment can be supported through incentives.

Farm-based treatment is never a singular measure for risk reduction, but, depending on local conditions, it may be an important component of an incremental risk management strategy. Its value comes to expression in combination with other measures, such as safer irrigation practices and post-harvest food safety measures. The reader should thus feel encouraged to use the cases presented here as examples for local adaptation and upgrading. They address on-farm ponds, filter systems and conventional irrigation infrastructure.

1. Pond-based on-farm water treatment systems

In many countries smallholder-farmers in urban and peri-urban areas use ponds, dugouts, drums or concrete tanks for various reasons. Dugouts and ponds may collect surface flow or subsurface flow near streams (Figure 1), function as storage reservoirs for pumped drain or stream water, or simply reduce walking distances to water sources where watering cans are the means of irrigation (Figure 2). Where the slope allows, farmers may link their ponds or reservoirs via narrow trenches in a network which can further reduce manual water transport (Figure 3). These types of informal irrigation infrastructure offer obvious opportunities for pathogen reduction e.g. through sedimentation, even at small scale.

Pond systems are widely used as simple, low-cost but effective biological wastewater treatment systems in many countries, not only in low-income countries. They remove helminth eggs and protozoa cysts mainly by sedimentation, while pathogenic bacteria and viruses are removed by a combination of factors that create an unfavorable environment for their survival. As long as the required retention times can be maintained most of these processes also work in small on-farm ponds.

To facilitate water collection, especially in smaller wastewater drains or streams, farmers block the water flow with sand bags or other materials, to create deeper pools suitable for watering cans. Often it is also possible to create cascades of small dams which offers further options for sedimentation processes (http://video.google.com/videoplay?docid=-7881268516571430438hl=en). Table 1 shows different forms of pond-based systems commonly used in developing countries, with potential to contribute to point-of-use wastewater treatment.

TABLE 1. Overview of informal pond-based water 'treatment' systems in smallholder agriculture

	On-farm sedimentation ponds	**"Chinese"-3-tank system**	**In-stream dams**
Description	Already installed small ponds, dugouts, drums or tanks (2-10 m^2 surface) used for interim wastewater storage. Usually, water is fetched from these reservoirs with watering cans while they are filled by small pumps.	To upgrade a one-pond system for an undisturbed retention time, three ponds are a preferred option: one pond is being filled by the farmer, one is settling and the settled water from the third is being used for irrigation. The pond size should exceed the daily water needs.	To ease water collection in wastewater drains and streams farmers block the water flow to create pools with sand bags or other materials. These constructions can form cascades suitable for trapping helminth eggs (see also Table 3).
Area requirement and/or size of ponds	Varies with crop water needs (i.e. crop type and climate) and the size of the cropped farm area		Varies widely but usually between 1 and 3 m^3
	In West Africa: Pond volumes vary in general between 2 and 10 m^3.	See left	
Pathogen removal	Studies in Ghana show that a two-day period of settling removed almost all helminth eggs from the water (reduced to less than 1 egg per litre) and about 2 log units for coliform bacteria. However, ponds are often used every day or every other day resulting in lower reductions, especially when their volume is small.	A one-day period of quiescent settling removes almost all helminth eggs and can achieve a 1 to 2 log unit reduction of other pathogens. The longer the water can 'rest' the better.	With more than one barrier helminth egg sedimentation can be significant. Fecal coliform reductions of 2 log units were found in Accra. If sand bags are perforated and closely packed, they can also function as sand filters.
Challenges	Stepping into ponds or touching the bottom with the watering can will stir up settled pathogens (training needed). Having alternative ponds will increase retention time (see right). Avoiding runoff of manure or contaminated water/soil into ponds.	Labour to dig more ponds than usually used. Pumps useful to fill ponds from streams. See comments for ponds left.	Sand bags might be washed away in the rainy season. Two or more barrier systems are preferred.
References	Keraita et al. (2008a, 2010); Reymond et al. (2009)	Mara et al. (1996)	IWMI (2008ab)

Figure 1: Dug-out on a vegetable farming site in Kumasi, Ghana, close to a highly polluted stream.

Figure 2: Interconnected tank system in Lomé, Togo (the water source here is shallow groundwater).

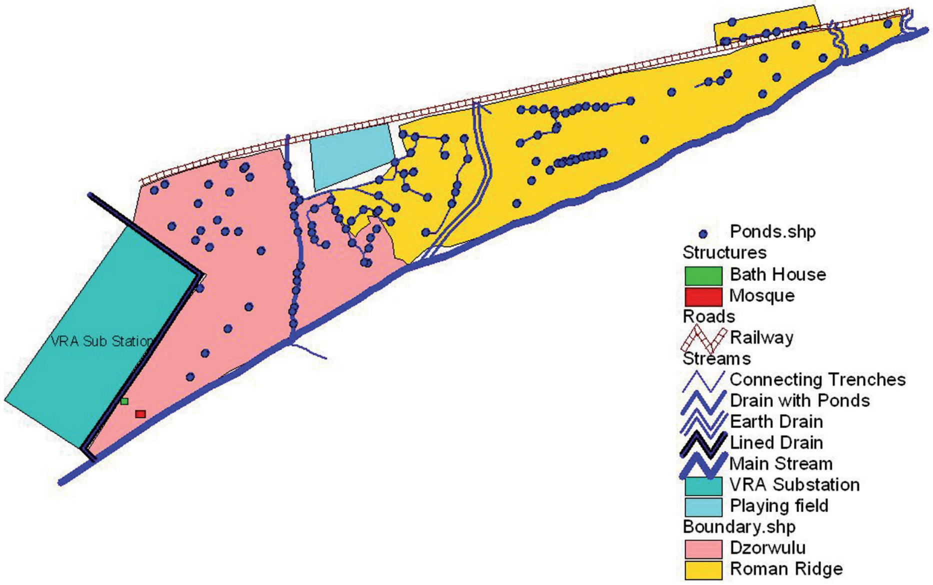

Figure 3ab: Distribution of individual and interconnected ponds and dugouts on a farming site in Accra, Ghana, drawing water via pumps from polluted streams and wastewater drains (see also Box 1).

BOX 1. Ponds as possible breeding sites for mosquito vectors

Pond-based systems are potential habitats of mosquito vectors of diseases like malaria, filariasis and different types of encephalitis or snail intermediate hosts of schistosomiasis. Contrary to the conventional wisdom that anopheline vectors of malaria only breed in rather clean water there are increasingly indications e.g. from Pakistan, Tanzania, Nigeria and Ghana, that some anopheline species also breed in polluted water sources (Mukhtar et al., 2003; Sattler et al., 2005). The actual occurrence however, can vary between seasons, from region to region and the type of wastewater (raw or diluted); therefore, programme managers or extension officers should put in place vector surveillance plans with the support of health authorities. Where schistosomiasis is endemic, water contact should be prevented and sanitation facilities improved.

In hyper-endemic malaria situations (such as those prevailing in many parts of sub-Saharan Africa) wastewater ponds might not pose a significant additional risk, but in meso-endemic areas like in Asia control measures will be important. These can be natural predators such as tadpoles which are often present even in smaller ponds. Small ponds could also be covered with netting while larger systems may need other methods of biological control e.g. larvivorous fish like Tilapia (Homski et al., 1994).

BOX 2. Improving on-farm ponds for wastewater treatment in Accra, Ghana

Location: A large vegetable farming site in Accra where polluted stream and drain water is the common irrigation water source for about 100 farmers. Individual ponds and networks of interconnected ponds are common (see Fig 3.). Networks are managed by two to over 20 farmers depending on their size. These systems enhance fecal coliform removal from 10^6-10^7 MPN/100ml by at least 2 log units from the wastewater source to the last pond. As for individual ponds, a removal of 1-1.5 log units was observed over two days. Helminth eggs were only occasionally found in the water source at this site (up to two eggs/litre) and dropped below one egg/litre in the first pond. A pilot project was initiated to upgrade an existing 5-pond network for enhanced risk control. The project was carried out in a participatory way with the farmers. Design modifications aimed at doubling the water volume and reducing "short-circuiting" (rapid flow), to increase the overall water retention time in the systems from one to two days.

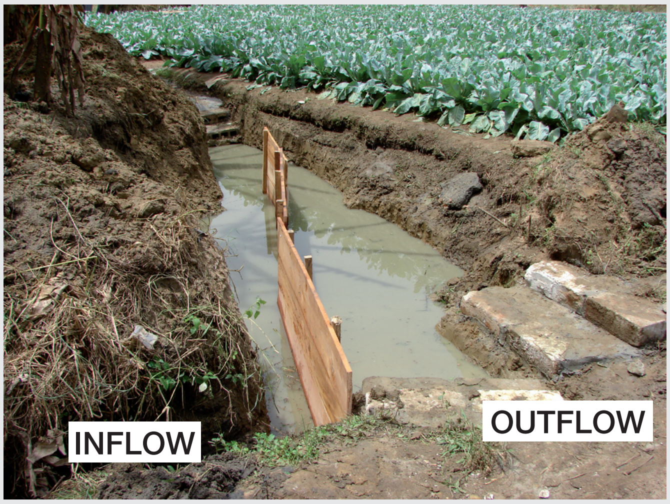

Figure 4: Interconnected pond with hardwood baffle.

Technology Description: Trenches were slightly widened and ponds were deepened and their shape regularized. Some stairs were built to facilitate water fetching without risk of re-entrainment of sediment. Simple baffles were placed in transit ponds to increase the retention time of the water (see figure 4).

Required inputs: Mostly labor for construction (two man-days) and USD50 per farmer for construction materials.

Pathogen removal: First results indicate that the retention trenches account for a quite stable permanent improvement and a flood gate (weir or pipe-elbow that can be turned) installed to stop the continuous inflow of pathogen-rich water from the main stream during the watering period prevented re-contamination.

Adoption and out-scaling potential: Pathogen reduction should ideally take place before or in the first pond to increase food safety on the whole site. Thus further 'upstream' experiments have been started. While this case does not illustrate a perfect solution, it shows that systems farmers are already implementing on their own initiative can contribute to pathogen reduction and also offer opportunities for improvements through participatory research. Important site criteria in this case were space, sufficient tenure security to allow the set-up of infrastructure and an adequate slope to allow flow by gravity for interconnected systems. Given the load of two 15 l watering cans, 50 beds per farmer and 10 watering cycles per bed over the day, every reduction in transport facilitates farmers' cooperation. The system is not suitable in areas prone to flooding.

Reference: Reymond et al. (2009).

2. Filtration systems

Table 2 shows some common filtration systems for treatment of wastewater at farm-level, using media such as sand, gravel or soil. In general, pathogen removal is achieved by a) retaining pathogens by straining and adsorption in the media and b) die-off and predation. The first two examples in Table 2 are about technologies that have been introduced, the third and fourth filtration techniques are about technologies that are already traditionally used by farmers.

Figure 5: Well next to a wastewater channel in Ouagadougou, Burkina Faso.

TABLE 2. Overview of common filtration systems for on-farm water treatment

	1. Slow sand filters	**2. Gravel sand filters for greywater treatment**	**3. Soil filter systems**	**4. Strainers**
Description	Used for example in water containers feeding *drip irrigation systems* where unfiltered wastewater tends to clog the outlets. Sand should be of correct configuration i.e. effective size of 0.15–0.40 mm and uniformity coefficient of 1.5-3.6.	Used in confined soil trenches, e.g. to treat greywater from small streams or households before irrigating crops and flowers. See Box 3 for an example.	Wells are sunk one to five metres away from wastewater streams or canals with the aim of collecting shallow groundwater as observed in Burkina Faso, Mali and Ghana. Canal water passes through the soil to the well following a hydraulic gradient and is filtered in the process (see Fig. 5).	In Togo, Ghana and Senegal, farmers use various materials like mosquito netting to prevent particles like algae, waste and organic debris from entering the watering cans while fetching water. Filtration materials are also attached to pumps.
Pathogen removal	0–3 log units for bacteria and 1–3 log units for helminthes (WHO 2006). In Ghana, 0.5–1m deep column sand filters removed about 2 log units of bacteria and 71–96% of helminthes.	Gravel under anaerobic conditions facilitates biological treatment with retention times of 2-3 days. Pathogens and total suspended solids were reduced to 50%.	Pathogen removal depends on soil properties (texture) and subsurface flow distance. Most effective for larger pathogens like protozoa and helminthes but less effective for removal of bacteria and viruses.	Positive side-effect is that pathogens adsorbed to the sieved organic matter are removed. Depending on the kind of matter and pathogen load, up to 1 log unit removal for bacteria and 12–62% for helminthes was observed with a normal nylon cloth.
Challenges	Clogging of the filtration medium (sand) makes frequent cleaning necessary.	Depending on location, cleaning to prevent odors and with time clogging of the gravel media.	Cracks in soil structure or termite tunnels can allow pathogens to pass through without being filtered.	Fine material which is most effective for egg removal without affecting water in-flow or out-flow. Continuous removal of filtered residues.
References	Metcalf and Eddy, Inc., (1995); Keraita et al., (2008b).	Bino et al., (2008) WQSD (2009).	Cornish and Lawrence (2001), IWMI (unpub.).	Keraita et al (2008b, 2010).

BOX 3. Confined trench gravel filter system for greywater treatment in Jordan

Location: The technology has been tested on different sites in Jordan, for example in Karak it has been used for over four years to water olive trees, and downstream of the Jerash refugee camp where the water is used for horticultural production for over one year.

Technology description: The system can support a large garden or horticultural enterprise. Downstream of the Jerash camp, greywater from a near-by stream is diverted when needed by a tube to the trench. In the photo, the water enters the trench in the back section where the transparent plastic sheet is perforated to allow water infiltration (Figure 6). From there the water moves slowly by gravity through gravel layers towards the container in front. The confined trench is lined with a dark impermeable plastic sheeting about 400 micron thick and is filled with gravel. In Karak there is three m3 of gravel medium 2–3 cm in diameter. The designed retention time is 2-3 days after which the filtered water enters the container through a perforated lower part. From here the water is pumped into a larger tank supporting an irrigation system. One unit can treat up to 240-300 litres a day, which is sufficient to irrigate about 20 olive trees throughout the year.

Figure 6: Treatment trench at Jerash, Jordan

Economic assessment: In Karak, the cost of one unit was estimated at USD120 for site preparation, gravel, plastic sheets and PVC pipes. The additional installation of an electric pump, electric wiring and drip irrigation would result in a total cost of USD300. This amount could be halved using a treadle pump. The average annual operation and maintenance costs were estimated to be USD39. Based on the Net Present Values and benefit-cost ratio of 2.6-2.7, which were calculated for different interest rates over 5 and 10 years, the system proved to be economically feasible.

Pathogen removal: While it was reported for the farm site near the Jerash camp that pathogens and total suspended solids were reduced to 50%, crops irrigated at Karak showed fecal coliforms within allowable limits for restricted irrigation.

Adoption and up-scaling potential: Suitable for small farms that have access to external or internal wastewater streams. Adoption could be high, especially in drier climates and in locations with strict enforcement of water quality standards. Capacity building is necessary for proper operation and maintenance. Odor from the system could pose a challenge if people live nearby.

References: WQSD (2009), Bino et al. (2008)

3. Use of irrigation infrastructure

Though not designed for pathogen removal, some components of irrigation infrastructure such as weirs (Figure 7ab) and storage tanks in irrigation schemes can significantly improve the microbiological quality of domestically polluted water. In the case of the Musi River which passes Hyderabad in India, the natural remediation efficiency of the river system, aided by the construction of irrigation infrastructure, particularly weirs, was very high. It was found to reduce fecal coliforms, helminth eggs, BOD and nitrogen at rates comparable with the treatment efficiency of a well designed waste stabilization pond system. The results showed a significant improvement in water quality over a distance of 40 km with 13 weirs, probably due to different remediation processes principally: sedimentation, dilution, aeration, natural die-off and exposure to UV-light. Weirs proved to be particularly effective traps for helminth eggs (Table 3).

Based on the large number of eggs found in the sediment of irrigation channels, it is recommended to modify the design of suction pipes on motorized water pumps to minimize the intake of sediment. An option might be U-shaped pipe ends which reduce sediment intake (Keraita et al., 2010).

Figure 7ab: Weir downstream of Hyderabad, India and in Northern Laos.

TABLE 3. Use of irrigation infrastructure for pathogen reduction

	Weirs and tanks
Description	Water reservoirs and weirs in irrigation canals can facilitate pathogen removal. • In irrigation schemes in Hyderabad, India, weirs, which are used for regulating irrigation water, act as efficient traps for helminth eggs. • The same principle can apply to dams constructed by smallholders (see Table 2).
Pathogen removal	The study along the Musi river showed that over a 40 km stretch of the river • Helminth eggs had reduced from 133 eggs/l to zero. • *E. coli* levels showed a reduction by over 4 log units from 7 log units per 100ml.
Challenges	The positive impact of natural processes for pathogen elimination and options to enhance them via standard irrigation infrastructure should be considered before investing in conventional wastewater treatment. The design and maintenance of irrigation infrastructure could benefit from consideration of its possible positive impact on pathogen levels (e.g. via sedimentation and sediment management).
Reference	Ensink et al (2010)

To take advantage of existing farm infrastructure and/or to build new ones requires full farmer participation, especially where risk awareness is low, regulations are not enforced and marketing channels (or demand) for safe produce are still lacking. Participatory on-farm research should be supported by awareness creation and the exploration of social marketing strategies and possible incentives (e.g. increased tenure security, credit) to facilitate technology adoption.

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