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DESIGN CONSIDERATIONS AND CONSTRAINTS IN APPLYING ON-FARM WASTEWATER TREATMENT FOR URBAN AGRICULTURE

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Abstract

In Accra, Ghana, one of ten SWITCH focus cities, the LA through the working group on water use for urban agriculture, initiated participatory action research activities on technological innovations to minimise risks associated with urban water reuse for agriculture within the context of integrated urban water management. The purpose was to demonstrate the potential of on-farm wastewater treatment to minimize health risks associated with urban water reuse for agriculture. The Demo focuses on further development of existing farmers' practice of on-farm water storage ponds, for improved irrigation water quality and volume. This study component of the demo addresses the problem in an integrated manner. It focused on farmers' constraints to propose sustainable and reproducible technical options. Research was held in Roman Ridge farming area, Accra, Ghana. Two different settings were investigated: 1) greywater derived from gutters in a ponds-trenches system; 2) individual ponds filled periodically with water pumped from a stream. Analyses show a natural faecal coliform removal of about 2 log units from the wastewater source to the last pond in the case of ponds-trenches system. As for individual ponds, a removal of 1-1.5 log units is observed in two days. Nutrients levels were very low, meaning that this water can't be seen as a source of fertilizer.

Main constraints towards improvement of on-farm water quality were found to include: limited available space, permanent demand for water, variability of water needs and watering schedule, walking distance to the water source, difficulty to dig deep ponds and trenches, risks of flooding, risks of nuisance for the neighbourhood and farmers' lack of financial resources. These have to be taken into account in any proposed modification. Design options chosen consist of slight modification favouring natural pathogen removal processes, i.e. increasing the volume of water, avoiding short-circuiting and hydraulic dead zones with baffles, improving water fetching points to avoid resiltation, introducing plug flow retention ponds between the source and the fetching points and creating retention ponds upstream in the drains. The two main aims are to increase the retention time of water and avoid recontamination of the water through resiltation or runoff. Design modifications were implemented on-site and are currently being tested.

Keywords: wastewater treatment, participatory action research, water quality

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INTRODUCTION

According to WHO guidelines (WHO 2006), pathogen contamination on vegetables from urban agriculture should be addressed through a multiple barrier approach, allowing via several interventions to achieve pathogen concentrations that do not threat human health. The WHO guidelines give some options for non-treatment of wastewater, such as choice of crops and drip irrigation etc. These options are applicable only under certain conditions. Till now, very few applicable solutions have been tested and validated at farm level. The research community is encouraged to identify other methods which could be successful in a given local or regional context and to verify their risk reduction and adoption potential (Drechsel *et al.* 2008b).

In Accra the SWITCH programme engages stakeholders in a Learning Alliance (LA) to drive research and demonstration activities and disseminate their benefits through knowledge sharing on urban water management across sectors within the city. The process identified major challenges in urban water management to which several SWITCH research themes respond. One of them is the use of urban water (fresh and wastewater) for agriculture and other livelihood opportunities. This is SWITCH Workpackage (WP) 5.2. Within the LA, a Working Group (WG) is set up to undertake study on this component and come up with recommendations for the LA. The LA-WG identified the need for research and demonstration on water use for urban agriculture (UA) and for development of guidelines for minimization of health risks. Against this background, SWITCH through the LA-WG, initiated participatory action research and demonstration on on-farm water treatment.

In Accra, Ghana, vegetables produced by urban agriculture are consumed by about 200,000 Accra residents daily (Obuobie *et al.* 2006). Amoah et al. (2007a) identified the farm as the main point of lettuce contamination. Besides irrigation water, contamination was also attributed to manure application and contaminated soil (Amoah *et al.* 2005). Urban farmers in Ghana perceived many of the risk reduction measures suggested in the international guidelines as unsuitable and identified simple and low-cost measures which they could easily adopt (Keraita *et al.* 2008a).

(Keraita *et al.* 2008a) found that only few farmers in Accra and Kumasi perceive the risks related to pathogen content in the water they use for irrigation. It is therefore very difficult to make them do efforts to improve water quality without incentives. The authors proposed incentives such as improved health to farmers, higher economic returns for safer vegetables and institutional support from government institutions. However, such incentives need further work and are only previewed for the middle to long-term.

In the same study, farmers identified among others the following key factors to be addressed to enhance the adoption of safer practices: (i) technical know-how on design of ponds and shallow wells, irrigation methods and scheduling; (ii) challenge of implementing the measures during water scarcity; (iii) need for measures which will not increase farmers' labor inputs; (iv) unwillingness and inability of farmers to put larger capital investments on measures. According to them, loss of income, level of investment needed, (market) incentives and land tenure appear key factors constraining or driving technology change in irrigated urban vegetable farming.

Dugout ponds are widely used in irrigated urban vegetable farming sites in Ghana (Keraita *et al.* 2008b). In most cases, they are used as intermediate water storage reservoirs filled either by surface runoff or by pumping water from polluted urban streams. Such reservoirs not only significantly reduce the walking distance to the stream, they also have a potential to reduce pathogens in irrigation water through die-off and sedimentation (Drechsel *et al.* 2008b; Keraita *et al.* 2008b). Another method , commonly used by farmers is to direct water from drains to ponds that are linked together through trenches. The dynamics of such systems and their potential for pathogen removal have not been studied yet, although such systems are very common and, if well designed, may have an important potential for pathogen removal.

This study investigates farmers' practical constraints to adoption and lays a basis for trials of appropriate and reproducible on-farm pond design modifications. It is based on an approach linking field observations to informal discussions with farmers with scientific research. This allows an understanding of the dynamics in ponds-trenches network and assesses natural pathogen removal efficiency in such a system, as well as in dugout ponds. Thus, two different settings were investigated: 1) greywater derived from drains in a ponds-trenches system; 2) individual ponds filled periodically with water pumped from a polluted stream.

The hypothesis we are testing is that with individual ponds, using dual ponds so that there is a minimum residence time created could reduce pathogens. That pond-trenches network could be modified to improve the pathogen removal efficiency in the system.

Research was carried out in Roman Ridge farming area, in Accra, Ghana. Water samples were analyzed for faecal coliform and helminth eggs. This study describes:

- How ponds-trenches systems work, the pathogen removal naturally achieved by such a setting and the constraints they imply for on-farm wastewater treatment.
- Assess the pathogen removal in sedimentation ponds with two ponds used alternatively by the farmer.
- The experience of working with farmers to modify water collection systems to improve pathogen removal.

METHODS

Study site

The Dzorwulu-Roman Ridge area has been chosen as SWITCH[1] demo site because of its large number of farmers (about 50), secure land for cultivation, huge range of market crops, secure water source, the existence of a farmer association on Dzorwulu side and the adoption by the farmers of improved technology. In addition, there has been long–term occupation by farmers (the proximity of the land to high tension poles had provided some protection against the land being developed for other purposes). Covering an area of 8.3 ha, this site is one of the largest urban agricultural sites in Accra. About 130 ponds are scattered on the site, some of which are linked together with trenches. They are fed through wastewater derived from drains, stream water or pipe water. Groundwater can't be used at the study site because of salt intrusion from the sea (Drechsel *et al.* 2008b).

Sampling

In order to assess the pathogen removal it was necessary to undertand the dynamics of the ponds-trench system and sample the water quality changes over the systems. Our samplings targeted the following information:

- Description of water dynamics in ponds-trenches system
- Analysis of water quality from the source to the last pond in ponds-trenches networks.

[1] SWITCH – Sustainable Water Improves Tomorrow's city Health is an EU funded project on integrated urban water management. Accra is one of ten SWITCH demo cities in the world. (www

- Observation of environmental factors and agricultural practices likely to influence water quality: watering practices, crop development stage, manure management, runoff, dredging, weeding and rain.

For trench-pond systems, samples were taken Samples were taken every day for periods of about five days continuously. For individual ponds, water samples were taken over 1 cycle of use (ie empty-full-empty). Sampling points were been selected for the following criteria:

- For pond-trench systems, in order to show the changes that may take place over the entire length. Samples were taken at the source, in one pond in the middle of the network and in the last pond.
- Farmers use the pond frequently: to draw conclusions, the pond sampled should be used daily and be surrounded by an important farming activity.
- Wish of the farmers to cooperate and to accept experiments and modifications of design.

Sampling was carried out before irrigation, at around 6.30 am and towards the end of the morning irrigation period, between 9 and 11 am. Samples were placed in a cooling box to minimize growth of coliform before analysis.

This study was carried out between November 2008 and April 2009, during the dry season.

Parameter analysis

The following parameters were analysed: :

- On-site: pH, temperature, conductivity. These three parameters have been measured with a portable pH-meter.
- Microbiological analysis: faecal coliforms, helminth eggs.
- Chemical analysis: dissolved oxygen (DO), and, for some samples, nitrate (NO_3), ammonia (NH_4^+) and phosphate (PO_4)

The Most Probable Number (MPN) method was used to determine faecal coliform counts. A set of triplicate tubes of MacConkey broth supplied by MERCK (MERCK1 KgaA 64271, Darmstadt, Germany) was inoculated with sub-samples from each dilution and incubated at 44°C for 24 to 48 hours (APHA-AWWA-WEF 2001). The number and distribution of positive tubes (acid or gas production or color change in both) were used to obtain the population of coliform bacteria in water samples from the MPN table. Helminth eggs were enumerated using the USEPA modified concentration method (Schwartzbrod 1998) identified using morphological features like shape, size and colour. The Bench Aid for the Diagnosis of Intestinal Parasites (WHO 1994) was used for preliminary identification.

Assessing hydraulic retention times

Hydraulic retention time and actual residence time are critical for understanding the pathogen removal and die-off that takes place for pond design modification. Water retention time depends on a multitude of factors such as storage volume of ponds and trenches, rate of withdrawal, and location of withdrawal point. Whereas it is quite easy to measure the volume used per day on a particular day, it is not easy to extrapolate the yearly average volume or the maximum volume that is used because the number of beds watered varies (they are not always cultivated) and the quantity of water applied per bed varies as well, according to the maturation stage of the crop and the use of watering cans or pumping machines.

Identification of farmers' constraints and motivations for design modifications

Farmer's constraints and motivations were identified with the help of (i) field observations, (ii) informal discussions and (iii) experience gathered while implementing different design modifications. About 20 farmers were working in the study area including migrants from Burkina Faso. .

RESULTS

Typology of source-to-plot wastewater pathways

Three different settings were identified in the study site:

1. *Ponds-trenches networks*: greywater is derived from drains, which are blocked with sand bags to allow for build-up of water so that it flows under gravity through trenches towards ponds dug on the farming sites. The networks may sometimes divide into different branches, flowing in different directions, to serve as many beds as possible. They may sometimes unite again further, but commonly there is no exit for the water except through withdrawal. Water flows according to the *communicating vessels principle* (in physics, *hydrostatic paradox*). Consequently, the level of water is the same everywhere as long as the ponds are all connected. The water level of the whole network is determined by the water level of the source, i.e. the level of the dam in a drain. Thus, it behaves like a single water body and not like a ponds-in-series system.
2. *Individual ponds:* water is pumped from a stream and directly into single ponds which usually belong to one farmer.
3. *Direct fetching in the drains* which are blocked in places to create a pool of water upstream, to make fetching easier. Water flows continuously, as in a stream. If there are several dams, this setting can be compared to ponds in series.

Farmers choose the one or the other option according to convenience. Indeed, walking distance between the fetching point and the beds is an important criteria for the farmers in locating the ponds (Drechsel *et al.* 2006). In the case study, flow rate in the drains is highly variable, but mostly not more than a few litres per minute, so that it becomes necessary to block it in order to have sufficient head to fill the ponds and trenches, or sufficient ponding for purposes of pumping. On the other hand, water in the stream is abundant all year round. As only few farmers own a pump, they prefer gravity flow and dig pond accordingly. Indeed, fuel for pumping involves significant costs in farmers' budget and length of the hosepipes is a limiting factor.

At the field site there are diversity in number and size of ponds, dimensions of trenches and volumes of water involved (Table 1). Average depth of ponds is 0.4 m, which seems to be the minimum depth which allows farmers to fetch water comfortably. The volume of water in the trenches can be very significant, as in Network 1, where it constitutes about 45% of the total volume in the network. In some cases, trenches can thus be considered as important retention volumes. The surface watered from a particular network is highly variable, as all the beds are not always cultivated and some beds may also be watered from individual ponds.

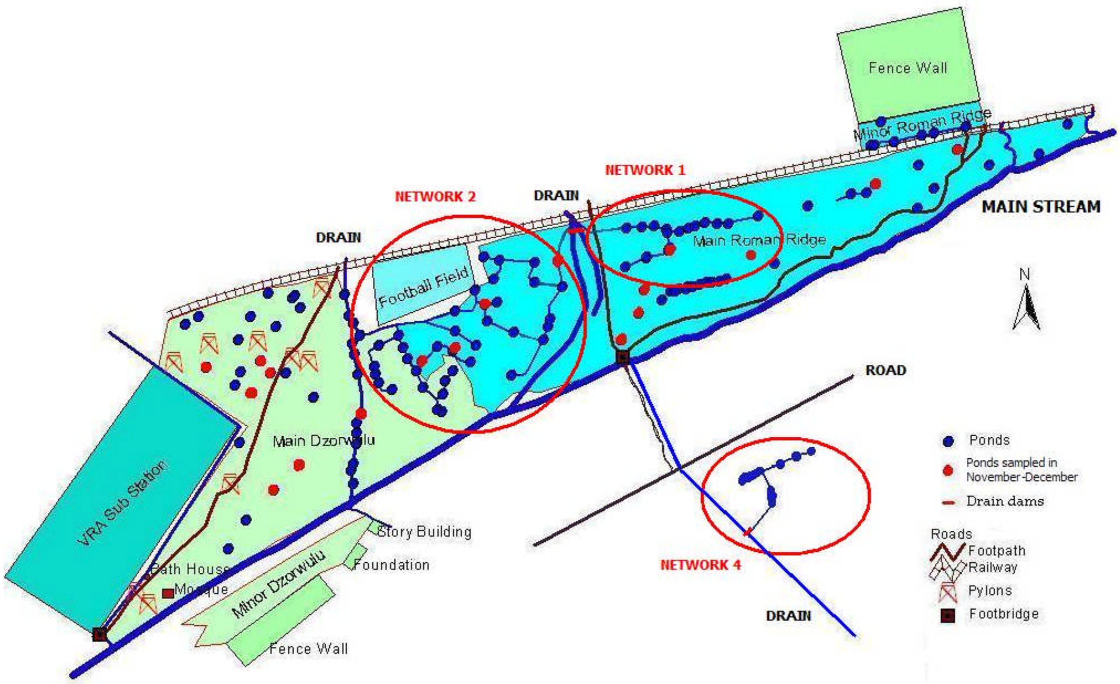


Figure 1: Map of the study site in Roman Ridge farming area, with sampling points and surface areas watered from Network 1 and the two selected individual ponds.

Table 1: Characteristics of the ponds-trenches networks under study

	Network 1	Network 4
Source of water	*greywater (dam on a drain)*	*greywater (dam on a drain)*
Number of farmers	~ 10	2
Number of ponds	14	5
Total length of trenches (m)	169.7	52.6
Total volume of water (m3)	43.3	11.9
in ponds	24.2	10.7
in trenches	19.1	1.2
Related farming area (ha)	~ 0.7	~ 0.3
Related number of beds	~ 250	110
Max watered surface (ha)	~ 0.4	~ 0.16
Average volume of ponds (m3)	1.7 *(1.1)*	2.1 *(0.7)*
Average depth of ponds (m)	0.4 *(0.04)*	0.4 *(0.1)*
Average width of trenches (m)	0.5 *(0.1)*	0.3 *(0.1)*
Average depth of trenches (m)	0.3 *(0.1)*	0.15 *(0)*

Individual ponds are often deeper than ponds linked with trenches. This is attributed to the fact that, unlike the latter, individual ponds double up as storage ponds, since these have to be filled using a pump which the farmers have to hire. Hence, farmers try to maximise volume and minimise surface area so as not to lose cultivable land. Average depth of the individual ponds studied is 0.9 m for a surface area of about 16 m^2, leading to a water volume of about 12 m^3 when full. Such volume is sufficient for irrigation for about 3 days. From a size/capacity perspective, these ponds are in the upper range of those investigated , in Kumasi, Ghana (Keraita *et al.* 2008b).

Water dynamics in ponds-trenches systems

We found that theoretical hydraulic retention time (HRT) is in all case very short, between half a day and three days for the investigated networks. The mean retention time may even be shorter, because of hydraulic short-circuiting and hydraulic dead zones (Shilton and Harrison 2003b). Moreover, retention times vary a lot between the different ponds of a network, depending on where water is fetched. In the first fetching points of a network, water may flow directly from the drain, leading to episodes with null HRT.

The modifications proposed here are aimed to increase the retention time between the water source and the first fetching point, and to increase the distance the water has to travel before reaching the latter. Indeed, the treatment efficiency of pond systems is often compromised by poor hydraulic design (Shilton and Harrison 2003a). Position of inlet and outlet is of particular importance (Shilton and Harrison 2003a; Shilton and Harrison 2003b). We observed on our study sites that short-circuiting very often happens in the ponds-trenches systems, because of inlet and outlet being placed closed together or because of important hydraulic dead zones. Short-circuiting could be avoided by the use of baffles (Shilton and Harrison 2003b) or by better location of trenches.

Assessing hydraulic retention times

It was observed that more water is applied when a pump is used, as the effort is much less important than with watering cans. It is important to quantify the maximum amount of water used, in order to ensure a certain quality of water all year long.

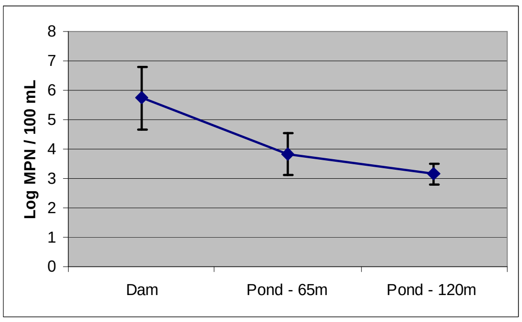
We recommend assessing the volume of water withdrawn from a system with different methods, which allows to account for variability. Multiplying the total number of beds by the average number of watering cans used per bed gives an idea of the maximum volume of water needed. In this case, capacity of a watering can is 15 L, average surface area of beds is 16 m^2 and average number of watering cans applied per bed is 10. Direct counting of the number of watering cans applied in one day can then be used to calculate.

Microbiological and chemical analyses

Faecal coliforms in ponds-trenches networks

There was a natural faecal coliform removal of about 2 log units from the wastewater source to the last pond (Figure 2).

A – Network 1



b – Network 4

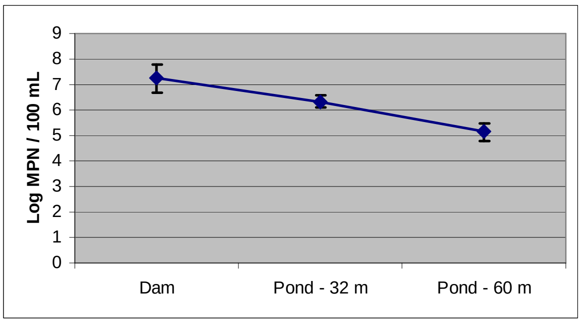
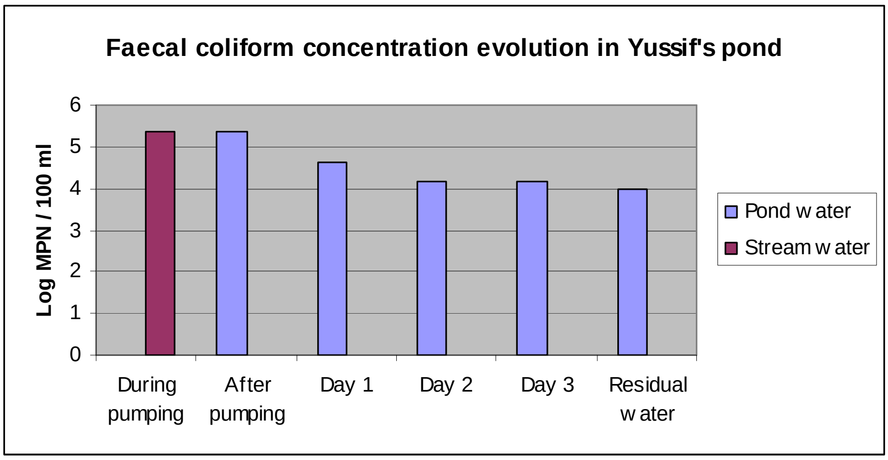


Figure 2: Evolution of faecal coliform concentrations along (a) Network 1 (mean of 10 samples for the ponds and 5 for the source) and (b) Network 4 (mean of 7 samples). Ponds are named according to their distance to the water source (drain in both cases). Error bars show the standard deviation.

Faecal coliforms in individual ponds

In individual ponds, a removal of 1-1.5 log units is observed in two days.



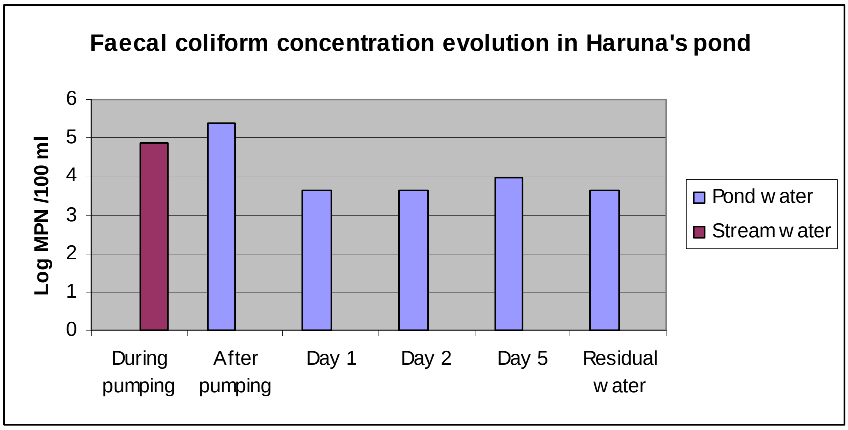


Figure 3: faecal coliform concentrations in two individual ponds

Helminths in water and sediments

Out of a total of 138 samples of irrigation water taken in Dzorwulu/Roman Ridge farming area, 110 samples did not contain helminth egg, and 14 contained 1 egg per litre only. It means that 90% of the samples matched WHO standards for irrigation water (WHO 2006). The remaining samples contained very low concentrations even lower than in the previous studies by Amoah *et al.* (2005).

On the ponds-trenches network, 68 out of 75 water samples, did not contain any eggs, 6 contained 1 egg per litre, and 1 contained 2 eggs per litre. It means that 99% met WHO standards.

Dissolved oxygen

Very low concentrations. Ponds are anaerobic to facultative.

Farmers' constraints and motivation for design modifications

The Key factors motivating farmers to modify design water source was the possibility to increase the volume of available water and reduce distances between water fetching points, and improving visual quality of water through design modifications. Incentives proposed were (i) loan of tools to facilitate their work, (ii) hiring of additional workers for digging, (iii) supply of cement to build proper steps to fetch water and (iv) improvement of visual quality of water..

Farmers did not have proper tools like shovels and picks at hand, because they lack the financial means, live far from their house and do not have facilities for safe storage of tools. As a result they dig their ponds and trenches only to a minimal depth and volume. Our study shows that farmers may need tools at the end of the rainy season, when ponds and trenches need rehabilitation due to siltation and collapse of ponds induced by heavy rains. At other times of the year farmers cannot effect repairs because of their permanent need of irrigation water. Consequently, scheduling of loans of tools at this time may have a stronger impact. Since farmers seldom dig the pond themselves but use hired labour, offering to pay for this is a major incentive to improve the condition of the ponds.

Ease of fetching water is important to farmers, as occupational health risks like muscular pains are linked to manual water fetching and irrigation with watering cans (Keraita *et al.* 2008a). Supply of cement to build proper steps to fetch water proved to be an efficient way to improve water quality, as it prevents farmers from disturbing sediments (Keraita *et al.* 2008b). Cement is not expensive as half bag is sufficient for one fetching point. Farmers supply the sand and stones themselves. Large and durable stones are available for a very low price near demolished buildings.

Our field trials showed that (i) digging of retention ponds between the drain and the first water fetching point and (ii) introduction of baffles to channel the water in the trenches, can improve the visual quality of water and reduce odor at the water fetching points, while improving water quality by increasing the retention and settling times. These measures are welcomed as farmers' perceptions of levels of pollution in irrigation water relies a lot on physical indicators like color, odor and effects on productivity (Keraita *et al.* 2008a). Impact of these design modifications on water quality are currently being tested and will be the topic of a further publication.

Farmer's needs to influencing on-farm design modifications

The study confirms there are major constraints towards improvement of on-farm water quality This is also consitent with the reports of identified by other studies (Faruqui *et al.* 2004; Mubvami and Mushamba 2006). The following were identified during the discussions with farmers:

(i) lack of space for extending ponds, as land is at a premium

(ii) continuous demand for water preventing regular rehabilitation and improvement ,

(iii) variability of water needs and watering schedule which makes designing less precise,

(iv) walking distance to fetch the water which limits the scope of design,

(v) difficulty to dig deep ponds and trenches which limits retention times,

(vi) risks of flooding and heavy rains which destroy structures,

(vii) risks of nuisance for the neighbourhood by creating stagnant ponds and breeding grounds for mosquitoes; and

(viii) farmers' limited financial resources. preventing investments for improved design.

In effecting design modifications it was therefore understood that the factors based on farmer's needs, that will influence uptake would be, no or limited loss of arable land, low cost modifications, use of cheap and easily available materials, no permanent infrastructure, no change in water fetching points and no impact on watering practices.

(i) Minimising the use of space

Many farmers don't have a large farming areas, so that every square meter counts for them, especially when they are lent a few beds to earn a minimal living. Moreover, soils are often poor, e.g. very sandy. Design modifications of ponds and trenches should consequently not involve further land uptake.

(ii) scheduling pond modifications with farmers to avoid disruption

Farmers need water permanently. However, ponds and trenches need to be dried out in order to increase their volume manually. In practice, this doesn't happen very often as farmers need significant amounts of water, sometimes more than the volume of the system itself for one single day. As mentioned above, modifications should be scheduled with farmers. We also found that choosing a period during which beds are fallow, will allow the farmers to spread the extracted materials over the beds,which will solve the problem of disposal of extracted materials and allows incorporating nutrient-rich sediments into the beds. However in areas where high helminth counts are observed in the wastewater, the sediments should be disposed of elsewhere as they concentrate the eggs.

In the ponds-trenches networks studied where water is derived from a drain, we found that maintaining the inflow of a sufficient quantity of water during the period of design modification may be an issue. Water contained in the system may just be sufficient for one day of irrigation, which means that the system should be supplied through the whole day to avoid water shortage. However, flow in the drains is not constant since it follows the diurnal pattern of wastewater flow. Farmers indicated that morning flows were important and constituted an important time for filling ponds. Preventing wastewater from filling the ponds in the morning, while they were in use, to avoid recontamination of ponded water, led to a shortage of irrigation water for the day.

(iii) Accomodating variability of water needs and watering schedule

We observed differences in volume of water used per day, and also the timing of irrigation. Both depend largely on the type of crops, their stage of development and the use, of a pump or not. For instance, seedlings need less water in the evening, as they are quite sensitive and have to be watered always with watering cans as the force of water from pumps can damage them. On the other hand, mature cabbages demand a lot of water, and farmers frequently use pumps to meet this demand. These are aspects that have to be taken into account when planning water management in a farming area.

Besides, farmers often do not farm only, but have different jobs during the day, like gardening or security, and work on their farm only in the early morning or late afternoon. Sometimes, they may also have different farming plots on different sides of the city. This affects their watering schedule as well.

(iv) Minimising walking distance to water

Considering that irrigation can take 40-75% of the time farmers spend on the farm (Drechsel *et al.* 2006), walking distance matters. What is more, carrying two watering cans of 15 liters each is a big effort, especially when it is repeated dozens of times in a few hours. For this reason farmers always seek the shortest distance to fetch water. This needs to be factored in when planning the fetching points. It is important to understand that under field conditions, the existing practices and locations have been optimised my farmers and should be maintained as far as possible.

(v) Understanding farmer constraints to digging deep ponds and trenches

We found that increasing the volume of water manually in ponds-trenches networks requires more than simply drying the system. Digging may be very hard, especially in clayey soils. Farmers usually hire external labour for this, as it is a difficult, time-consuming, and expensive activity. Farmers therefore usually stop at the minimal depth allowing them to fetch water easily (i.e. around 40 cm). It is only when space is limited or in the case of individual ponds, that they sometimes dig deeper. For improving water quality, Keraita *et al.* 2008b, recommended a water depth of 60 cm to significantly reduce re-suspension of sediments. This implies that without the incentives mentioned above, farmers are unlikely to dig to the recommended depth, as the effort would be too big for the expected benefit.

(vi) Accounting for risks of flooding and heavy rains

Due to their location in lowlying areas to access water, many urban farming areas are prone to flooding during the rainy season, from May to August in Accra. When ponds and trenches are immersed in running water, it is clear that they will suffer from important input of earth and sand. At the end of the rainy season, farmers have to rehabilitate them. Since this is a recurring practice every year, they prefer not to dig the ponds too big or too deep. This also meant that putting in place a more permanent infrastructure would mean protecting it against flooding.

We therefore considered the possibility of improving treatment by building two or three dams in the drains themselves to augment treatment action prior to directing into ponds. However, practice showed that during heavy rains, dams are destroyed by the water flow. In effect farmers use less permanent infrastructure precisely to accommodate strong flows in drains. However, it also means that no permanent infrastructure can be built in such drains, unless it is planned with the government and built in a way to accommodate climatic and environmental conditions during storm events but simultaneously gurantee enough water for the farmers in normal times.

(vii) Reducing nuisance to the neighbourhood

The dams that the farmers build on the drains create areas of stagnant water, liable to become mosquito breeding areas and to release unpleasant smells, especially if they turn anaerobic. Conflicts may then arise between the farmers and the neighbours. This was the case in our study area. This aspect should also been taken into account when modifying drains for water treatment upstream. In our case, the number of dams that can be placed in the drain is limited to two, as an informal settlement is present 80 meters upstream of the farming site.

(viii) Realise farmers' limited financial resources

A good example of this is farmer use of pumps : they will use it only as required, because fuel has a significant cost. For our design purposes this means that we cannot propose a solution that requires pumping to maintain the system.

We proposed for instance that they install baffles to improve water quality. This is worth testing as the impact can be important and will provide good information for the design of future networks. However, it must be recognised that it is unlikely that individual farmers will invest in baffles.

DISCUSSION

Pathogen removal compared between on-farm ponds and waste stabilization ponds

Waste stabilisation ponds prove most of the time to be inappropriate for on-farm treatment, in particular because of lack of space to accommodate extended retention times, and lack of land tenure, to accommodate these permanent structures. Similarly simple technologies like ponds in series (facultative, maturation ponds) can't be implemented on farm primarily because of lack of space, but also because one has to rely on gravity flow to minimise costs, and the on farm conditions we studied, do not allow for this. We also observed significant differences between the ponds we investigated and waste stabilization ponds: ponds studied are not eutrophic, do not have large amounts of algae and do not have high dissolved oxygen concentrations (often 15 to 30 mg/L in WSP) and high pH (often 8.5 to 9.4 in WSP). Under such conditions, faecal coliform removal cannot be as effective as described in the literature (Parhad and Rao 1974; Pearson *et al.* 1987; Curtis *et al.* 1992a). Above all, retention times observed in Accra are very short. They may not even reach one day, which is negligeable compared to those found in conventional wastewater treatment plant (20-40 days).

Understanding of water dynamics may be a great help to propose simple and effective design modifications, inspired by experience gained with waste stabilization ponds (Shilton and Harrison 2003b). This study shows that natural pathogen removal occurs in ponds-trenches network, and there's an important improvement potential with simple design modifications.

Important parameters should be added in further research on on-farm wastewater treatment. Effect of macrophytes and biofilm has been shown to be important for water purification (Polprasert and Agarwalla 1994; Polprasert and Agarwalla 1995; Kone 2002). Macrophytes increase biofilm surface areas and organic load elimination (Kone 2002) but also prevent visible light to penetrate the water and hence lower beneficial action of algae. It should be investigated where and when they should be used in ponds-trenches networks and individual ponds. Protozoa may also be important (Barcina *et al.* 1997; Chabaud *et al.* 2006), as well as micro-invertebrates such as Daphnia.

Natural Pathogen removal and die-off

Faecal coliform concentrations in on-farm ponds correspond to those found in previous studies (Amoah *et al.* 2005; Amoah *et al.* 2007a). Our study completes these results by giving them a spatial dimension, with an analysis of the evolution of concentration throughout the ponds-trenches networks. For individual ponds, Keraita *et al.*2008a, observed that farmers did not consciously leave water to settle and that no care was taken by all farmers when collecting irrigation water. Use of two ponds in alternation, and construction of steps at the fetching points to minimise disturbance as proposed in this study, can contribute to solving this problem. Keraita *et al.* 2008b, studied sedimentation over a period of 12 days. In practice, such a duration is very seldom achievable, as water in such ponds is usually used in 3-5 days. The same authors found that, in contrast to the reduction of worm eggs, the die-off of coliforms was only significant during the dry season. Our study was conducted during the dry season. A repeat of the experiment during the rainy season should be made to compare results.

The low levels of helminth eggs in our wastewater samples show that helminth eggs are not always a problem in urban populations . From this analysis of samples may safely assume that greywater flowing from this middle-class areas is unlikely to contain high levels of helminths. It is advisable to assess every situation independently, without assuming high helminth eggs levels in the wastewater, and building specific treatment units to respond to this.

There's also a need to assess bacterial flows in the system, and the contribution to crop contamination from different field sources. Different authors have pointed the importance of soil and manure for pond water contamination and direct crop contamination (Drechsel *et al.* 2000; Amoah *et al.* 2005; Seidu *et al.* 2008). Such studies have not yet been undertaken.

Farmers' motivations

Although farmers are often not aware of health risks inherent to the use of wastewater, for themselves and for consumers; and although they are not willing to invest money to improve water quality, we found that they are always willing to have more available water and to improve the ease of fetching water. Such a situation may lead to win-win arrangements between farmers and health officers : increasing the volume of water increases the retention time, thus potentially improving the water quality, and improving water fetching points allows to reduce the re-suspension of sediments. This should be a basis for any on-farm design modifications.

Our study shows that to increase co-operation, it is important to help famers at the times most convenient for them. Also, very often, farmers lack appropriate tools for digging and construction work, which is a limiting factor for them to increase the storage capacity of their ponds and trenches. Construction and digging activities are also dependent on farming schedule, which itself is variable. Especially, ponds and trenches are rehabilitated at the end of the rainy season. From our field observations, this is the best moment to help them with incentives, and trigger positive design modifications. Thus farmers are encouraged to dig deeper, and may even be willing to do the work themselves.. We surmise that lending tools is a small investment, but, in this context, lent at the right moment, is a very important step in a participatory process with benefits for everyone.

Implications for Integrated Urban Water Management

In the long term, and in a perspective of Integrated Urban Water Management (IUWM), the best solution seems to adapt the drains upstream for agricultural purposes downstream (upstream action). Of course, this can only be made in partnership with the decision makers. A system of floodgate installed in the drains themselves should allow creating retention ponds during the dry season and letting the water flow freely during the rainy season. From the right beginning, drains should be made much wider upstream from farming areas to be able to store large volumes of water.

Experience also shows how heavy the lack of land tenure could weigh on the possibility to build permanent installations. IUWM would mean that areas are given precise purposes and that everything is made to serve these purposes. A farming area should gain the status of farming area, which would allow the realization, by the farmers and by the government, of infrastructures aimed at farming. Adequate water quality can't be achieved when ponds can't be deep and big and where efforts are periodically destroyed by the rain.

CONCLUSION

This study has shown that it is possible to work with farmers and to implement on-farm design modifications with them. In such an intervention, we conclude that most challenges and lessons learnt have a social dimension. Farmers have constraints which in turn influence the techniques that can be applied and the way they are applied. Flexibility is necessary for research on the field. Obtaining science based results under field conditions is a big challenge but it is important to gain an in-depth understanding of all the influencing environmental, social, and economic factors to enable a more integrated design for on-farm improvement to water quality..

Future studies should focus on the impact of simple design modifications favouring natural pathogen removal processes, such as increasing the volume of water, avoiding short-circuiting and hydraulic dead zones with baffles, improving water fetching points to avoid resiltation, introducing plug flow retention ponds between the source and the fetching points and creating retention ponds upstream in the drains. In this study such design modifications have been implemented on-site and are currently being tested. Results will be the topic of a further publication.

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