Using on-farm sedimentation ponds to improve microbial quality of irrigation water in urban vegetable farming in Ghana
B. Keraita, P. Drechsel and F. Konradsen

ABSTRACT
This paper presents an assessment of the potential of using on-farm ponds to reduce levels of microbial contamination in wastewater-contaminated irrigation water. The study involved observations on the use of ponds in urban agriculture in Kumasi, Ghana, and more than 300 irrigation water samples were taken for physico-chemical and microbial laboratory analysis. The study shows that while on-farm ponds are commonly used, their potential to remove pathogens through sedimentation has not been fully optimized. Two-thirds of helminth eggs were in the sediments and careful collection of irrigation water without disturbing sediments reduced helminth eggs in irrigation water by about 70%. Helminth eggs reduced from about 5 to less than 1 egg per litre in three days in both dry and wet seasons while thermotolerant coliforms took six days in the dry season to reduce from about 8 to 4 log units per 100 ml, to meet the WHO guidelines. For optimal pathogen removal, better pond designs, farmers’ training on collection of water with minimal disturbance and any other means to enhance sedimentation and pathogen die-off can be essential components of a multiple-barrier approach complementing farm-based measures like simple filtration techniques, better irrigation methods and post-harvest contamination.

Key words | microbial water quality, on-farm sedimentation ponds, urban farming, wastewater

INTRODUCTION
Irrigated urban vegetable farming is practiced worldwide and is increasingly becoming a livelihood to many urban dwellers and an important means of attaining balanced diets and urban food security (WHO 2006). For instance, in Accra, Ghana, about 1000 farmers are involved in market-oriented urban vegetable farming and vegetables produced are eaten by about 200,000 Accra residents daily (Obuobie et al. 2006). However, in Ghana as in other low income countries, the irrigation water sources used are heavily polluted with untreated wastewater due to poor sanitation in urban areas (Scott et al. 2004). High levels of microbial contamination in irrigation water, equivalent to untreated wastewater, have been recorded in urban vegetable farms in Ghana (Amoah et al. 2005). This has raised public health concerns, especially as overhead irrigation is common and some of the vegetables grown are eaten raw, hence the need for sustainable solutions to reduce the risks.

Treatment of wastewater using waste stabilization ponds (WSP) can reduce wastewater irrigation risks significantly as it is effective in removing pathogenic microorganisms (Mara 2004). Helminth eggs and protozoan cysts are mainly removed by sedimentation while pathogenic bacteria and viruses are mainly removed by a combination of various factors that create an unfavourable environment for survival (Curtis et al. 1992; von Sperling et al. 2004). In Ghana, wastewater treatment is done mainly using WSP, but less than 10% of urban wastewater is treated. This makes source treatment of wastewater not a
feasible option in the short-term to reduce wastewater irrigation risks. On-farm treatment using WSP is also not possible, especially in urban farming where land is limited due to the large area required for implementation. However, at farm level waste storage and treatment reservoirs (WSTR) can be used and significant removal of bacteria and helminth eggs has been reported (WHO 2006).

In Ghana, ponds (dugouts) usually less than 5 m diameter and 1 m deep are widely used in irrigated urban vegetable farms. In most cases, they are used as storage reservoirs where surface runoff and wastewater effluents are channelled for irrigation. Like WSTR, sedimentation of pathogens could take place, hence these on-farm sedimentation ponds (OFSP) could be a simple and cheap measure to reduce pathogen levels in irrigation water. This study was therefore conducted to assess the effectiveness of these OFSP in improving microbial quality of irrigation water.

METHODS

Study area

The study was conducted in two urban vegetable farming sites, Karikari (KAK) and Gynyase (GYN) in Kumasi, Ghana, which produce more than 70% of most vegetables in Kumasi, especially lettuce. Land is very limited, with each farmer having about 0.1 ha and with no tenure security. OFSP are used as sources of irrigation water. GYN is more than 10 ha and has about 35 vegetable farmers. It is located on a narrow inland valley with a small stream. The OFSP at GYN mainly get water from surface runoff from upstream villages and farms, though in the rainy season some get shallow groundwater. At KAK, there are about 10 farmers, with farms located in a residential area, but this study was restricted to only one part of it about 1 ha in size. The farmers at KAK mainly use greywater from the households which is channeled into the ponds in earthen drains. In both sites, irrigation of vegetables is done manually using watering cans. Ponds are therefore dug close to vegetable beds to lessen the distance of carrying irrigation water which is very labor intensive (Drechsel et al. 2006). The furthest vegetable bed is an average 15–20 m away from the pond. When collecting water, farmers usually walk into the ponds and often scratch the pond beds, especially when volumes in ponds are low, causing resuspension of the already settled sediments.

Data Collection

Pond measurements

Measurements were taken on six ponds at KAK and twenty five ponds randomly selected from the upper, middle and lower parts at GYN.

Physico-chemical parameters

Water samples were taken from twenty randomly selected ponds from both sites for physicochemical analysis. Parameters analyzed were electrical conductivity, turbidity, pH, nitrates (NO$_3^-$N), ammonia (NH$_3$–N), phosphorus (P) and potassium (K). Sampling and laboratory analysis followed standard procedures as described in APHA-AWWA-WEF (1998).

Microbial parameters

To assess the effect of sedimentation on removal of microbial organisms, water samples were taken from a) settled ponds b) disturbed or unsettled ponds and c) sediments. Settled water samples were taken early in the morning before farmers used the ponds, unsettled water samples were taken during irrigation and at least 2 hrs after taking settled samples and sediments were taken after irrigation and from the lowest parts of the ponds i.e. near the bed of the ponds. To establish sedimentation rates, trials were restricted to KAK for better control and monitoring. Four new ponds with similar characteristics as other OFSPs were constructed for controlled monitoring. Each pond was 1 m wide and 0.6 m deep. Initial filling for all ponds was done from the same water source for uniformity. The ponds were not used for irrigation and minimal disturbance was ensured when taking the samples for laboratory analysis. Sampling followed standard procedures (APHA-AWWA-WEF 1998). Table 1 shows more details of the sampling frame.
Table 1 | Sampling for water for microbial analysis

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Location/Season</th>
<th>No. of ponds</th>
<th>Pond status</th>
<th>Sampling duration (days)</th>
<th>Sampling interval (days)</th>
<th>No. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influence of sedimentation</td>
<td>KAK</td>
<td>6</td>
<td>Settled</td>
<td>42</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unsettled</td>
<td>42</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sediment</td>
<td>42</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>GYN</td>
<td>6</td>
<td>Settled</td>
<td>42</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unsettled</td>
<td>42</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sediment</td>
<td>42</td>
<td>7</td>
<td>36</td>
</tr>
<tr>
<td>Sedimentation rates</td>
<td>GYN-Dry</td>
<td>4</td>
<td>Settled</td>
<td>12</td>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>GYN-Wet</td>
<td>2</td>
<td>Settled</td>
<td>12</td>
<td>1</td>
<td>48</td>
</tr>
</tbody>
</table>

Analytical methods

Settled and unsettled water samples were analyzed for thermotolerant coliforms and helminth eggs but sediments were only analyzed for helminth eggs. The Most Probable Number (MPN) method was used to determine thermotolerant coliforms. Ten fold serial dilutions were done. A set of triplicate tubes of MacConkey broth supplied by Merck (Darmstadt, Germany) was inoculated with sub samples from each dilution and incubated at 44°C for 24 to 48 hours (APHA-AWWA-WEF 1998). The number and distribution of positive tubes (acid or gas production or color change in broth) 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 2001) and identified using the WHO Bench Aid (WHO 1994). All species of helminth eggs were enumerated.

Data analysis

Statistical analysis was done with SAS for Windows System Version 9.1. Indicator organisms were normalized by log transformations. Other data analysis, graphs and tables has been done by Microsoft Excel and SPSS 11.0.1 for Windows (SPSS Inc., Lead Technologies).

RESULTS AND DISCUSSION

Characteristics of ponds used by farmers

OFSP which did not receive shallow groundwater had generally larger surface areas and greater depths, hence larger volumes. Large surface areas were to maximize collection of surface run-off and household effluents and greater depths were to enhance chances to get groundwater. This is shown by ponds at KAK, which had on average more than twice the volume of ponds at GYN (Table 2). Even at GYN, ponds on the upper side, which rarely receive groundwater, were on average 0.3 m wider and 0.1 m deeper than those on the lowest parts which had more access to groundwater.

The OFSP had irregular shapes. They had different shapes, but most of them were almost cylindrical with spherical bottoms. About 90% of ponds at GYN had sloping beds and edges which enables farmers to walk into the ponds to get water from the deepest ends, especially when

Table 2 | Sizes of sampled ponds at the study sites

<table>
<thead>
<tr>
<th>Farming site</th>
<th>No. of ponds</th>
<th>Depth (m)</th>
<th>Surface area (m²)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GYN</td>
<td>25</td>
<td>0.35–0.70 (0.47)*</td>
<td>1.23–10.46 (4.12)</td>
<td>0.55–6.27 (2.00)</td>
</tr>
<tr>
<td>KAK</td>
<td>6</td>
<td>0.50–1.00 (0.72)</td>
<td>2.14–5.94 (4.17)</td>
<td>1.03–19.00 (4.52)</td>
</tr>
</tbody>
</table>

*Figures in parenthesis are arithmetic means.
water levels dropped in the dry season. The remaining 10% of ponds at GYN and all ponds at KAK had vertical edges and horizontal beds and farmers collected water without walking into ponds. Ponds at KAK were always full with water, due to the steady supply from household effluents.

In principle, ponds with larger surface areas and shallow depths enhance bacteria pathogen die-off due to more exposure of water to sunlight (Pearson et al. 1995). On the contrary, deeper ponds may be more effective when used as sedimentation ponds, if minimal disturbance of the sediment can be maintained despite water flowing in and farmers fetching it. As land is scarce in urban farms, large sized ponds though more suitable for pathogen die-off, will be unreasonable. A balance is needed in designing ponds for removing both bacteria and helminths as well as reducing water losses from the ponds without making their design more labor intensive for the farmer.

Effects of sedimentation on levels of indicator organisms in irrigation water

Levels of helminth eggs and thermotolerant coliforms in settled ponds, unsettled ponds and sediments at the pond beds are shown in Table 3. Levels in both indicator organisms were slightly higher at KAK due to the use of household effluents. However, the location differences were not statistically significant. Wider variations were recorded in levels of thermotolerant coliforms in ponds at GYN than at KAK. The variations could be due to surface runoff that is collected in ponds at GYN, especially when it rains as its quality varies widely. Nevertheless, Levene homogeneity test showed the F statistic was not significant.

On average, a difference of about 1.0–1.5 log units of thermotolerant coliforms per 100 ml was obtained between settled and unsettled ponds. The levels in settled and unsettled ponds were significantly different at both KAK and GYN. No big differences in thermotolerant coliform counts were expected as the principle removal mechanism for thermotolerant coliforms is die-off (Mara 2004). However, removal through sedimentation can occur from adsorption of bacteria to particles in irrigation water (Sharma et al. 1985).

Sedimentation was even more effective in removing helminth eggs. Most of the eggs were found in sediments. On average, ten, five and one eggs per litre were in sediments, unsettled and settled irrigation water respectively regardless of the season and the levels were significantly different. This is in line with other studies which have shown that the highest concentration of helminth eggs is usually in the sediments (Nelson 2003; Karim et al. 2004). It is therefore important that sediments in ponds are not disturbed during water collection and even better, the sediments should regularly be removed for safe disposal.

Removal rates of indicator organisms

Rate of thermotolerant coliforms removal

Thermotolerant coliforms had an exponential decrease in the dry season. Removal rates were higher in the first days and slowed as retention progressed, with most removal taking place in the first six days. Similar observations were made by Athyde-Junior et al. (2000). Removal rates were much lower during the wet season (Figure 1). This was attributed to the rainfall, runoffs and lower daily sunshine durations during the wet season. While no rainfall was recorded in all the days of the dry season trials, it rained on

<table>
<thead>
<tr>
<th>Location</th>
<th>Pond status</th>
<th>No. of samples</th>
<th>Thermotolerant coliforms (log of MPN 100 ml⁻¹)</th>
<th>Helminths (No. of eggs litre⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAK</td>
<td>Settled</td>
<td>36</td>
<td>7.83 ± 0.54</td>
<td>1.3 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>Unsettled</td>
<td>36</td>
<td>9.26 ± 0.53</td>
<td>4.9 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>Sediment</td>
<td>36</td>
<td>Not determined</td>
<td>10.0 ± 1.1</td>
</tr>
<tr>
<td>GYN</td>
<td>Settled</td>
<td>36</td>
<td>5.57 ± 1.21</td>
<td>1.0 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>Unsettled</td>
<td>36</td>
<td>6.61 ± 1.18</td>
<td>4.3 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>Sediment</td>
<td>36</td>
<td>Not determined</td>
<td>9.4 ± 1.2</td>
</tr>
</tbody>
</table>
average once in every two days during the wet season. Daily
average sunshine duration over the dry season was 6.5 hrs
which reduced to about half during the wet season. Temperatures taken at 9.00 am also went down to 25°C in
the wet season from more than 27°C during the dry season.

Thermotolerant coliforms die-off rate in ponds is widely
accepted to follow Chick’s first order kinetic model
\( C = C_0 e^{-kt} \) \((\text{Pearson et al. 1995})\). From this equation,
the die-off coefficient \((k)\) is therefore the slope of the linear
regression line on a natural log scale of thermotolerant
coliforms \((C, C_0)\) verses time \((t)\). Adapting to this model in
this study, the \(k\) factor for thermotolerant coliforms was
found to be 1.62 and the regression coefficient was 0.87. In
a related study on die-off rates of faecal coliforms in a WSP,
a \(k\) factor of 1.07 was obtained \((\text{Johnson et al. 1997})\).

**Removal rate of helminth eggs**

There was a non-linear association between levels of
helminth eggs and sedimentation time (Figure 2). In three
days, levels of helminth eggs were less than 1 egg per litre but
most removal happened within the first day. After five days
of sedimentation, there were no helminth eggs in water.
Unlike thermotolerant coliforms, there was no significant
different in removal rates for helminth eggs between the dry
and wet seasons. This indicates the differences in removal
mechanisms. Helminth eggs removal was done mainly
by sedimentation. Factors such as sunshine duration
and rainfall which had high influence in removing thermo-
tolerant coliforms had less influence on removal rates of
helminth eggs. Due to their high density, helminth eggs settle
much faster, between 2 minutes and 2 hours in clean water,
than bacteria which can take several months \((\text{Dahi 1990})\).

In line with these findings, studies conducted on
wastewater in Morocco, showed that a 24 hr settling period
before treatment in algal ponds reduced the number of
helminths from 113 to 4 eggs per litre \((\text{El Hamouri et al. 1994})\). In the same study, further 3 – 6 days retention time
during treatment was able to reduce the number of eggs to
less than 1 egg per litre. This clearly shows that most
helminth eggs were removed during the first day of
retention. For a batch fed system, with low helminth eggs,
perhaps the first three days will be sufficient for removal to
zero levels. However, farmers in Ghana have to irrigate
continuously due to high crop water requirements. They
fetch water about 15 times each morning and each after-
noon from the same pond in all days except when it rains.
As helminth eggs can easily settle over night, it is imperative
to avoid sediment contact during the day

As sedimentation takes place, there is a buildup of
sediments with high concentrations of helminths in the
ponds. With time, the levels of helminths in irrigation water
may start rising again, especially when the buffer of a water
layer between the lowest level of water collection and
sediments is not adequate. This time depends mainly on the
rate of sediment buildup and volumes of water in the pond.
Therefore, other than restricting farmers from walking into ponds when collecting irrigation water, it is important that ponds are designed with right depths to avoid the suspension of sediments. Watering cans have an average height of 0.3 m. A quick assessment showed that giving an allowance of 0.2–0.3 m between the lowest level the watering can is dipped and sediments can minimize re-suspension significantly. Therefore, a 0.6 m water depth in ponds will be sufficient. Farmers will in this case, giving an allowance 0.2 m for water level, will have to dig their ponds about 0.8 m deep.

Influence of physicochemical parameters in removal of indicator organisms

Studies have shown the influence of physical and chemical parameters in improving microbial quality of irrigation water in ponds (Curtis et al. 1992). The levels of some of the parameters analyzed are shown in Table 4. Water in ponds had high levels of nitrates (NO$_3$-N), potassium (K) and phosphorous (P) likely deriving from fertilizers, manure and wastewater. P levels were particularly high as in the surrounding soil (Drechsel et al. 2004). High nutrient levels favor pathogen survival (WHO 2006). Nevertheless, it is not possible to influence the N-P-K levels and they contribute to agricultural productivity. Salinity levels and pH did not show any particular concern.

There was a wide variation of turbidity in pond water. Highest levels were obtained in ponds which contained low volumes of water. Two different impacts are possible. High levels of suspended solids in turbid water restrict sunlight penetration to the ponds reducing pathogen die-off. On the other hand, pathogens might be adsorbed to solid particles and move faster to the bottom of the ponds. In addition, in ponds with low volumes of water, samples were taken closer to the pond beds so higher turbidity could be due to other solid particles like sand.

### CONCLUSION

On-farm sedimentation ponds (dugouts) are used widely in urban vegetable farming in Ghana where irrigation water is highly polluted. This study shows that an average of two-thirds of helminth eggs in on-farm ponds were in the sediments. Therefore, careful collection of water without disturbing sediments could cut the helminth counts in irrigation water considerably. Most settlement of helminth eggs took place in the first day. Three days settlement could reduce the number of eggs to less than 1 egg per litre to meet the WHO guidelines. The duration was longer for thermotolerant coliforms, which showed significant reduction only during the dry season. It is however hard for farmers to leave water to settle for three days especially in the dry season when there is scarcity. Training is required on how to collect water with minimal disturbance of sediments at the pond beds, for the benefit of both farmers and consumers. Ponds also will need to be better designed in terms of depths and shapes and also the use of multiple ponds tested. The sizes of the ponds should however consider the actual plot size and often insecure tenure situation which might reduce farmers’ interest in investing labor. Measures that can enhance sedimentation and fecal coliform die-off like natural flocculants would be helpful. While on-farm wastewater treatment appears to have a potential especially as barrier for helminth eggs, complementary on-farm and off-farm measures like safer irrigation practices and salad washing will be important steps towards more food safety.

<table>
<thead>
<tr>
<th>Farming site</th>
<th>pH (7.2)</th>
<th>Conductivity (dS/m)</th>
<th>Turbidity (NTU)</th>
<th>NO$_3$-N (mg/l)</th>
<th>NH$_3$-N (mg/l)</th>
<th>P (mg/l)</th>
<th>K (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GYN</td>
<td>7.0–7.8</td>
<td>0.10–0.47</td>
<td>35–791</td>
<td>0.12–5.32</td>
<td>0.14–1.30</td>
<td>30.09–41.59</td>
<td>5.75–6.84</td>
</tr>
<tr>
<td>KAK</td>
<td>7.4–7.8</td>
<td>0.14–0.59</td>
<td>18–88</td>
<td>0.90–2.99</td>
<td>1.08–1.54</td>
<td>18.55–58.70</td>
<td>6.41–21.99</td>
</tr>
</tbody>
</table>

*Figures in parenthesis are arithmetic means.

†Four ponds had more than 500 NTU. Without them maximum and mean levels were 77 and 59 NTU.
ACKNOWLEDGEMENTS

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