Assessing water quality and health implications in informal peri-urban irrigation. Case studies from Nairobi and Kumasi

G A Cornish
HR Wallingford Ltd, Wallingford, UK
Gac@hrwallingford.co.uk

1 Setting the context

This paper draws lessons from work carried out in Nairobi, Kenya and Kumasi, Ghana, where research was conducted into the nature, extent and importance of informal, *irrigated* agriculture in the urban and peri-urban zones of those cities. The research was funded by the Infrastructure and Urban Development Department of the British Government's Department for International Development, (DFID). Fieldwork in Nairobi was carried out in collaboration with a number of independent consultants while in Kumasi the project collaborated with staff from the Institute of Land Management and Development at the Kwame Nkrumah University of Science and Technology.

Over the three year project the following studies were conducted in the two cities:

a) Water quality monitoring to determine possible health risks to irrigators and consumers.
b) Broad-scale scoping surveys to obtain initial quantitative data on the geographic distribution of irrigated cropping and its main technical and economic characteristics.
c) Detailed studies of selected farmers to obtain more accurate technical, social and economic data.

(See Cornish *et al* 1999; Cornish and Aidoo, 2000; Hide and Kimani, 2000; Cornish *et al* 2001; Hide *et al* 2001). In terms of a strategic process of gathering information on irrigation practices, for that information to inform and shape policy formulation or more immediate "project intervention", this work was a first step. It aimed to gather quantitative information on an aspect of urban and peri-urban agriculture (UPA) - irrigated crop production – for which there is little other quantitative information available.

The work was of limited duration and was confined to obtaining a 'snap-shot' of practices in the two cities. However, some consideration is given here to the practicality of using the same methods to achieve effective monitoring and evaluation of conditions over time.

The focus of this paper and the lessons drawn concern only that part of the research addressing water quality and its potential impact on producer and consumer health. The interest of this workshop is in the validity of the methods used to obtain information but the findings of the studies, and their conclusions, are used to illustrate the points made.

2 Water quality, irrigation and health

2.1 Water quality standards

A full consideration of water quality monitoring to determine the impact of its use in crop production might take account of the chemical, physical and microbiological aspects of quality. However, Mara and Cairncross (1989) assert that the health hazards due to chemical pollution are of only minor importance when considering the reuse of domestic wastes. Where industrial wastewater is an important contributor to overall pollution then heavy metals and other chemical trace elements may present a threat to the health of irrigators and consumers. Nevertheless, there are currently no guidelines for permissible levels of trace elements and heavy metals in wastewater used for irrigation which relate to the potential risk to human health as a consequence of crop uptake and bio-accumulation. Most authors cite either a table of phytotoxic thresholds prepared by the National Academy of Sciences (1972) and Pratt (1972), or refer to the WHO drinking water guidelines (WHO, 1993). These data are reproduced in Table 1.

Table 1 WHO and EU drinking water quality guidelines for heavy metals and threshold values leading to crop damage (mg/l).

Element	WHO drinking water guideline [a]	EU drinking water guideline [b]	Recommended maximum concentration for crop [c]
Arsenic	0.01	0.05	0.1
Cadmium	0.003	0.005	0.01
Chromium	0.05	0.05	0.1
Copper	2	0.1 – 3.0	0.2
Iron	0.3	0.2	5.0
Mercury	0.001	0.001	-
Manganese	0.5	0.05	0.2
Nickel	0.02	0.05	0.2
Lead	0.01	0.05	5.0
Zinc	3	0.1 – 5.0	2.0

Sources:
a WHO (1993)
b Cited by Chapman (1996)
c Cited by Pescod (1992)

The difficulties and cost associated with the accurate measurement of heavy metals and trace elements, coupled with the absence of reliable guidelines for their interpretation, mean that their monitoring, in any wastewater reuse situation, cannot be deemed a priority, although further research is required in this area. It is generally accepted that microbiological quality is the primary measure of the suitability of wastewater for irrigation, when considering the health risk to growers and consumers.

The past twenty years have seen considerable research carried out to evaluate the microbiological risks to health associated with the use of wastewater for crop irrigation, particularly with a view to developing design guidelines for the treatment of wastewater. In defining a "safe" microbiological water quality three different approaches may be used:

1. The absence of faecal indicator bacteria
2. No measurable excess risk of infection attributable to wastewater use
3. A modelled risk of infection which falls below a predefined level

(Blumenthal *et al*. 2000).

It is argued by many that the first approach, which has been widely adopted in the USA, is too restrictive and results in unnecessarily restrictive practices and high water treatment costs. It also leads to the apparent anomaly whereby water used for irrigation of crops likely to be eaten raw (unrestricted irrigation) must be of a higher quality – zero faecal coliform – than bathing water, where the US Environment Protection Agency permits a mean count of 200 faecal coliform / 100 ml, (USEPA, 1976).

The World Health Organisation (WHO) guidelines, first published in 1989 followed the second approach, (Mara and Cairncross, 1989). Following a major review of epidemiological studies that were available (Shuval *et al* 1986), supported by evidence from microbiological studies, microbiological quality guidelines were defined that it was considered would not lead to any measurable increase in infection risk. These set the level of faecal coliform for unrestricted irrigation at ≤ 1000 /100 ml, with an additional guide of ≤ 1 nematode egg / litre. These guidelines have been criticised by some as being too lax, (Blumenthal *et al*. op cit), but despite that they have been adopted by a number of countries.

Even this 'relaxed' value of 1,000 faecal coliform / 100ml for unrestricted irrigation is still more stringent than the bathing water quality standard applied in the UK which specifies no more than 2,000 faecal coliforms / 100 ml (DETR, no date).

Since publication of the WHO guidelines in 1989 further epidemiological studies have been carried out with the objective of further authenticating or revising the 1989 guidelines. This work was recently reviewed and summarised by Blumenthal *et al* (op cit) who set out recommendations for revising the WHO 1989 guidelines in accordance with the values in Table 2. In reaching their conclusions Blumenthal *et al* used both epidemiological studies and quantitative microbial risk assessment models, the third approach suggested above. They retain the value of 1,000 faecal coliform /100 ml for unrestricted irrigation but suggest a more restrictive limit of 0.1 (rather than 1) nematode egg / litre. For irrigation of cereal, fibre or fodder crops, pasture or trees, they now suggest limits for faecal coliform which vary depending on the irrigation method and the age of those exposed. There was previously no faecal coliform guideline for this category.

Table 2 Recommended revised guidelines for treated wastewater use in agriculture. (After Blumenthal *et al*, 2000)

Category	Reuse conditions	Exposed group	Irrigation method	Intestinal nematodes. mean no. eggs/ litre	Faecal coliform mean no. / 100 ml
A	Unrestricted irrigation. Vegetables and salad crops eaten raw. Sports fields	Workers, consumers, public	Any	≤ 0.1	≤1,000
B	Restricted irrigation. Cereal, fibre or fodder crops, pasture or trees.	B1: Workers, but no children <15yrs, nearby communities.	Spray or sprinkler	≤ 1	≤ 100,000
		B2: as B1	Surface	≤ 1	≤ 1,000
		B3: Workers, including children <15yrs, nearby communities.	Any	≤ 0.1	≤ 1,000
C	Localised irrigation of crops in category B, if exposure of workers and the public does not occur.		Drip/trickle	Not applicable	Not applicable

2.2 Direct and Indirect reuse of wastewater

In discussing quality guidelines for monitoring wastewater use in UPA it is important to emphasise that the figures set out by WHO, the USEPA and most other authorities are intended for use in the design of wastewater treatment systems. They indicate the target quality of the effluent leaving those systems if it is to be used in irrigation. Westcot (1997) makes the important distinction between this form of controlled reuse, which he describes as “direct reuse”, and the situation that prevails in many cities of the developing world where municipal and industrial wastewater is discharged into watercourses draining the urban area without any treatment at all. There is no control over the subsequent use of this water for crop irrigation, a situation that Westcot terms “indirect reuse”. Such indirect reuse is very widespread and is likely to increase as urban population growth outstrips the resources available to build waste collection and treatment facilities.

Although the WHO guidelines are intended for the design and monitoring of treatment works, Westcot acknowledges that it is “prudent” to use the guidelines for faecal coliform numbers as the quality standard to aim for in monitoring water quality where indirect reuse is known to occur. However, as there are no routine and simple techniques available to monitor helminth egg numbers in water samples Westcot considers it impractical to use the helminth guideline in routine and wide-scale monitoring of urban wastewater used for irrigation.

2.3 The recommended approach of the FAO

To ensure the safety of both producers and consumers Westcot (1997), writing in the FAO Water Report series, argues in favour of establishing a routine water quality monitoring programme. Such a programme, monitoring faecal coliform numbers, is used to support a certification programme certifying that high risk or restricted crops – mainly vegetables that are eaten raw – are produced in a safe environment. This in turn requires education of consumers and encouragement of market forces whereby consumers chose to buy only certified produce. It is argued that this approach is more realistic under conditions of disbursed and uncontrolled wastewater reuse than attempts to impose crop restrictions which are almost impossible to enforce. The report draws heavily from the example of Santiago, Chile, South America, where such an approach was adopted.

A programme of this type might be difficult to establish and sustain in the poorer countries of Africa, as our own field studies demonstrate. However, the approach merits serious consideration by any authority concerned for the health implications of peri-urban irrigation with wastewater. In particular the ranges of contamination and consequent recommendations put forward by Westcot provide a useful point of entry in any attempt to monitor and interpret water quality data for irrigation. These are summarised in Table 3.

Table 3 Ranges of Contamination and Recommendations (after Westcot, 1997)

Mean number of faecal coliform / 100 ml [a]		Recommendation
< 1,000	[$< 10^3$]	Appropriate for irrigation of vegetables
1,000 – 10,000	[$10^3 – 10^4$]	Potentially safe if the source of contamination (presumed to be localised) can be eliminated
10,000 – 100,000	[$10^4 – 10^5$]	Heavy contamination requiring treatment before the water can be used for unrestricted cropping
> 100,000	[$>10^5$]	Extensive heavy contamination – highly unsuited for irrigation.

Note: a. Based on a minimum of 5 samples taken over the irrigation season

In the example cited by Westcot wastewater irrigation occurred on a formal irrigation scheme downstream of Santiago. The physical layout of the scheme, with a single intake and the division of water amongst different distributary canals, leant itself to the development of a relatively simple monitoring programme. Samples from a small number of key locations throughout the scheme indicated the quality of water used by many hundreds of farmers. This in turn made the development and enforcement of a crop quality certification scheme, a practical option.

2.4 Water quality monitoring amongst widely disbursed irrigators

The situation for informal irrigated cropping around Kumasi and Nairobi, and many other urban centres, does not conform to this pattern. Rather than many farmers drawing their water from a common source or network that can be readily monitored, many individual farmers draw their water from different, uncontrolled sources. The source may be a river, drain or natural pool or a shallow well giving access to shallow groundwater. Under these circumstances it is not practical to establish a monitoring programme, either for a “snap-shot assessment” or routine monitoring, that provides comprehensive cover of all water sources used for informal irrigation. A more pragmatic approach must be developed using the following rationale:

Figure 1 **Steps in planning water quality monitoring for Informal Urban and Peri-urban Irrigated Agriculture (IUPIA)**

1. Identify areas within the urban and peri-urban zone with the greatest numbers of informal irrigators.

2. Identify the water sources used by farmers in those areas.

3. Determine the approximate number and frequency of samples that can be collected and analysed given the availability of financing and human and laboratory resources.

4. Allowing for a minimum requirement of 5 samples per site over the irrigation season, plan a sampling programme that will permit this frequency of sampling and cover those water sources and locations used by the greatest number of farmers.

Where water is drawn from many locations along river courses attempt to monitor quality trends along those rivers.

Where water is drawn from shallow wells in many different locations it is only practical to monitor a few representative wells. Focus on areas with the greatest density of wells.

2.5 Field experience in Nairobi and Kumasi

Before planning any sampling programme of our own, agencies in both cities were contacted to determine what routine water quality monitoring was already taking place. In Kumasi the Environment Protection Agency conducts annual spot sampling at a number of locations on the river system within the metropolitan area. A single sample per year is very little to allow conclusions to be drawn regarding quality, and sampling does not occur downstream of the metropolitan boundary. However, due to resource constraints more frequent and wider sampling is not possible. In Nairobi there is no routine water quality monitoring of any kind on the rivers draining the city. A joint initiative of the UNEP and two national NGOs had recently conducted sampling at 24 locations on the three main rivers running through the city but again only single samples were analysed from each site. This is an extreme snap-shot approach open to wide experimental error with no possibility of correction through use of monthly or seasonal mean data.

In Kumasi and Nairobi irrigators draw water both from the rivers running through the urban centres and from shallow dug wells. In Kumasi much of the irrigated production occurs on land well to the south of the urban limit but drawing water from a river which collects most of the urban run-off and municipal sewage. In both cities sampling sites were selected that would provide information on the decline in water quality in moving from upstream to downstream of the urban centres. Samples were also taken from two, randomly selected shallow wells. Large numbers of shallow wells are used for irrigation in both cities and to properly assess the water quality provided by these wells would require a much greater investment of resources. Sampling of just two provided a first indication of the water quality associated with such wells.

Table 4 **Summary of water sampling programmes in Kumasi and Nairobi**

City	No. of sampling sites	Period of sampling	Number of samples and Frequency
Kumasi	7 river sites / 2 wells	18th Feb – 16th March 1999 (26 days)	5 at 6 day intervals
Nairobi	3 river sites / 1 well 1 sewage outlet	4th Aug – 13th Sept 2000 (40 days)	5 at 10 day intervals

Table 4 summarises the sampling regime used in the two cities and Figures 2 and 3 show the mean numbers of faecal coliform recorded at different locations in Nairobi and Kumasi respectively. In both figures sites to the left lie upstream of the urban centre and sites to the right are downstream.

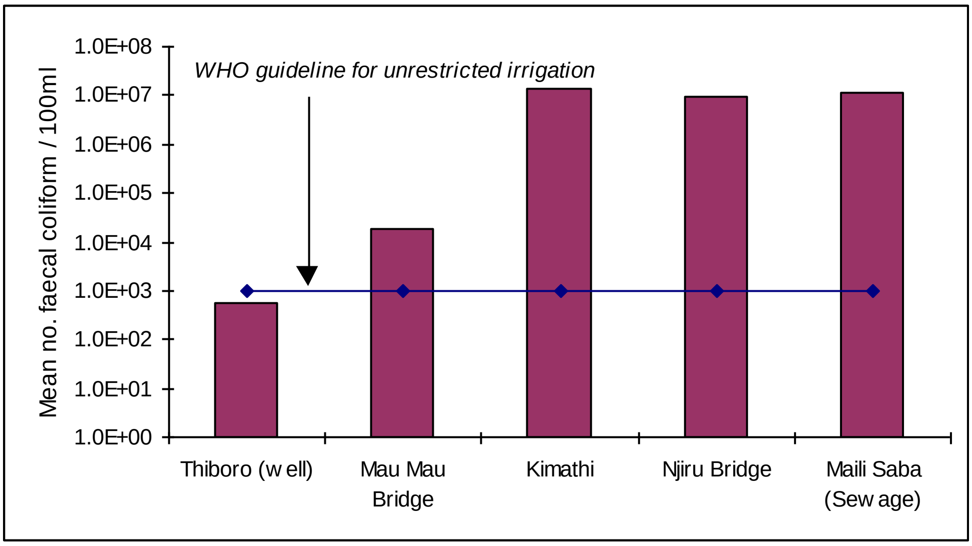

Figure 2 **Mean numbers of faecal coliform /100 ml at different sites in Nairobi (Mean of at least 5 sampling dates)**

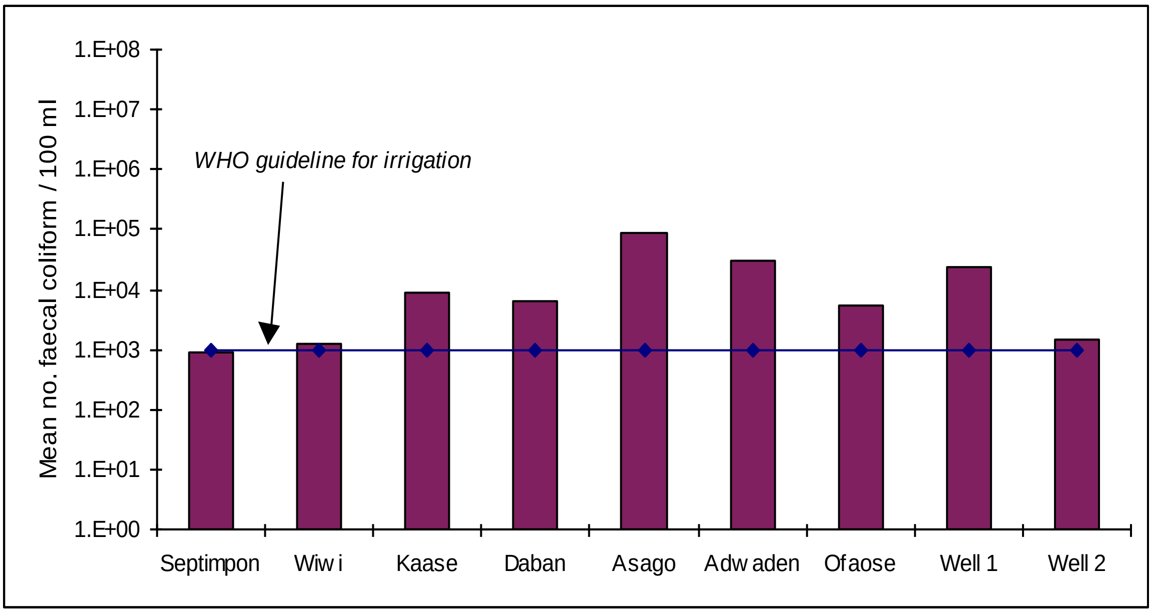

Figure 3 **Mean numbers of faecal coliform /100 ml at different sites in Kumasi (Mean of 5 sampling dates)**

The data from Kenya show generally very high levels of pollution. Numbers of faecal coliform in the Nairobi River at Kimathi and Njiru Bridge are as high as that recorded in effluent drawn directly from sewage mains at Mali Saba to the East of the city. This is 10,000 times greater than the recommended limit for unrestricted irrigation. Only water drawn from the shallow well at Thiboro, upstream of Nairobi City, yields water that lies within the WHO guidelines. In Kumasi levels of pollution are generally lower with two sites upstream of the city centre lying on or about the WHO threshold value and even the worst site exceeded the guideline by only 100 fold.

2.6 Longer term monitoring, participatory monitoring and making the results count

This paper is more concerned to review the procedures and resources required to obtain such data rather than discuss the findings themselves, although they indicate that urban and peri-urban irrigators in both cities pose a risk to their own health and that of consumers as many of the crops such as tomato and chilli pepper are often eaten raw.

In both cities, laboratories with technicians able to conduct the required analysis were available but in neither city is routine monitoring of surface waters used by informal irrigators taking place. This is partly a consequence of the very limited public resources available to fund such a programme but a second factor, possibly of equal importance, is the lack of awareness amongst health and environmental agencies of the scale of production that is underway using wastewater flows. The broad-scale surveys carried out around the two cities showed that in the study area around Kumasi, with a 40 km radius, there is an estimated 11,500 ha under informal irrigation. In the smaller, 20 km radius around Nairobi the area exceeds 2,000 ha. This project found it notably difficult to bring these findings, and information on the extent of informal urban and peri-urban irrigated crop production, to the attention of city authorities. In Kumasi, city representatives and staff from the Irrigation Development Authority, failed to attend a local workshop, despite invitation and in Nairobi there appear to be political sensitivities associated with the knowledge that farmers are breaking into sewers to obtain “water” for irrigation. The practice is tolerated, or at least not eliminated, possibly because it is not clear what practical alternatives could be offered and many households derive an important income fro200m the practice.

A parallel project in Kumasi, also funded by DFID, researching water quality and water resource management at the watershed level, (McGregor *et al* 2000) has adopted participatory monitoring of water quality as a means of bringing the issue to the attention of as many stakeholders as possible. Simple water quality testing kits have been given to a number of secondary schools and these are being used by classes to measure simple chemical – pH, dissolved oxygen – and microbiological parameters. School staff are being encouraged to interpret the data with their classes so as to heighten awareness of river water quality and its implications for drinking, bathing and irrigating. Schools are also making presentations to Community Committees and Water and Sanitation Committees. The data are at best approximate, depending on the skills of those using the kits, and there is no direct mechanism to record the data and set it before technocrats and policy makers. However, the approach can raise awareness of the importance of water quality amongst water users, including irrigators, potentially leading them to petition for actions to improve quality. In the absence of resources for regular formal monitoring and the possible lack of motivation on the part of policy makers to address water quality issues this approach may have much to recommend it, although it too relies upon external resources to supply the kits and renewable reagents and train the users.

2.7 Conclusions for water quality monitoring

- Because informal irrigated production is widely dispersed through the urban and peri-urban zone it is not possible to restrict water quality monitoring to a few select locations. A monitoring programme must provide wide coverage, attempting to monitor and quantify the inevitable deterioration in quality as surface waters pass through the urban zone. However, the selection of which surface watercourses to monitor and at what location, must be shaped by knowledge of where the largest areas of irrigated cropping lie.

- Monitoring the quality of numerous shallow wells that give access to shallow groundwater is more problematic as the quality of such water can vary greatly over short distances and individual wells may be exposed to point source pollution. The only pragmatic approach is to select and monitor a number of representative wells, the number determined by the resources available

- To provide a reliable picture of water quality a monitoring programme should take at least 5 samples spaced at intervals over the irrigation season.

- Monitoring of microbiological water quality through counting of faecal coliform indicator bacteria is straightforward and widely understood but the routine provision of field transport and laboratory reagents for even this level of monitoring is often difficult to secure. Procedures for monitoring the incidence of intestinal nematode eggs – the other WHO quality indicator – are far less widely known and as a consequence some authorities accept that they will not form part of a routine monitoring programme.

- Accurate determination of the concentration of heavy metals and other chemical pollutants requires access to very well equipped laboratories and skilled technicians. It may be possible to find such facilities within universities or within the private sector in many major urban centres. However, where the financial resources available to sustain routine water quality monitoring are very limited (as is generally the case) then priority should be given to establishing a network of sites where the regular and accurate monitoring of microbiological quality is ensured. Only after this is achieved should resources be used to monitor the more technically complex chemical parameters.

- Supply of simple water quality monitoring kits directly to the communities affected by water quality, provided this is supported by adequate training to permit interpretation of the results, may be an effective means of raising their awareness of the issues. This, in turn may achieve a more effective response from policy makers and planners.

3 Potential wider responses to the findings

Based on the field work conducted in Kumasi and Nairobi, which carried out the research described here and also obtained quantitative data on technical and economic characteristics of urban and peri-urban irrigators using farmer and community questionnaires, a range of potential actions or recommendations can be identified. These are discussed briefly here in the final section of the paper.

3.1 Acknowledge the existence and extent of informal irrigation

Policy makers and government departments will only formulate supportive policies and release resources for interventions when they recognise the scale and importance of irrigated cropping. This requires that they have reliable information on both the benefits that it brings – contributions to the urban food supply and household income generation – and the health risks associated with the use of polluted water for irrigation.

This research has drawn together quantitative information that can contribute to raising the awareness of policy makers and government departments, pointing them towards areas for practical action. However, informal irrigation is only one activity amongst many that are together described as urban and peri-urban agriculture. Although this sector is receiving considerable attention from UN agencies, NGOs and the research community it still has to vie with the demands of other sectors when seeking the attention and resources of policy makers and government departments. Irrigated cropping is an important part of urban and peri-urban agriculture, producing a large proportion of the fresh vegetables consumed in cities and providing the major source of cash income for thousands of households. At the same time, because many of the water sources used are heavily polluted both growers and consumers are at risk from bacterial and helminth infections. This combination of significant benefit and risk should motivate policy makers and government departments to actively review the actions that might be taken to enhance the benefits and reduce health risks associated with informal irrigation.

3.2 Co-ordinated interventions to address water quality

Use of water with levels of microbiological pollution well above WHO guidelines for irrigation is commonplace. However, bringing about improvements in current practices is not straightforward, given the nature of irrigation where hundreds of farmers work independently of one another drawing their water from many unregulated sources.

Any programme aimed at reducing the health risks associated with urban and peri-urban irrigation must be broad based. Such a programme must provide an incentive for producers and consumers to change current practice and make change possible without those groups incurring high additional costs. The technical and institutional resources needed to eliminate the use of polluted water for crop irrigation by informal irrigators should not be under-estimated. Westcot (1997) has described the characteristics of such a programme, and Beernaerts (2001) describes how elements of that approach might be applied in Accra.

3.2.1 Raising public awareness

Raising the awareness of producers and consumers of the health risks associated with the use of polluted water for vegetable irrigation can provide an incentive for change amongst consumers, traders and growers.

Where consumers are made aware of the potential link between produce irrigated with polluted water and the incidence of diarrhoeal disease within their households they can then pursue one of several options:

- Continue as before, making no change to their buying or food preparation practices
- Buy the same produce but take precautions in its preparation – thorough washing or cooking
- Reduce their consumption of those food items
- Demand alternative produce that is certified to be safe. Some consumers may be willing to pay a premium for this improved quality

Traders may be encouraged to maintain improved levels of hygiene in the storage, washing and presentation of produce – avoiding the use of dirty water to freshen produce. To achieve this, market traders must have easy access to clean water supplies. The traders may also pass on the demand of consumers to growers, seeking only to buy produce from farmers using clean water.

Where farmers are pressed by traders to supply "clean" produce or where premium prices are paid for "safe" produce they have an incentive to use clean water sources. However, alternative, cleaner water sources must be available to them and if premium prices are to be paid consumers need some form of assurance, through a system of certification, that produce has been grown using clean water.

3.2.2 Provision of clean water sources

a) Use of protected wells

The provision of alternative, clean water sources is a major challenge in many locations. Water drawn from shallow wells or dugouts might be expected to be less polluted than that in rivers draining urban centres. However, the water quality studies in both Kumasi and Nairobi showed the mean faecal coliform count in most monitored wells to exceed the WHO guideline of 1000 FC/100ml for unrestricted irrigation. The source of pollution in these wells is not known but there is a need for field research to determine if simple protection measures, combined with awareness raising amongst farmers, can raise the water quality to a level that consistently lies within the WHO guideline.

Where farmers are using motorised pumps to lift water from polluted rivers or other open water bodies, shallow wells do not provide a viable alternative unless the sustainable yield of the well matches the pumping rate, which is seldom the case. It may be appropriate to evaluate water quality and yields from specifically constructed well-points adjacent to polluted sources but such wells are costly and tie the farmer to one site.

b) Improving river water quality
In the long term, improving the microbiological quality of rivers and other water bodies will be the best solution but in many urban and peri-urban locations this remains an unrealistic goal in the short to medium term.

c) Controlled re-use of effluent
In some situations it might be more appropriate to promote the controlled re-use of treated effluent. Where sewage treatment infrastructure already exists adjacent to potentially cultivatable land it may be practical to encourage farmers to relocate from sites where they are using unsafe water to a new site where they have access to treated effluent. To be successful such an intervention requires that:

i) There is sufficient treated effluent to satisfy predicted irrigation demands
ii) Quality of the effluent is regularly monitored and the treatment process consistently delivers water that is "safe" for irrigation
iii) Farmers are willing to relocate. This carries major implications regarding housing, access to other services, access to market, etc.
iv) Consumers are confident that produce irrigated with treated effluent is safer than existing produce.

To ensure that these needs are met would require clear policy decisions to be made plus continuing expenditure of resources to maintain the treatment infrastructure and regularly monitor effluent quality.

3.2.3 Water and crop certification

Westcot (1997) discusses certification programmes and their attendant policy issues in detail. Certification that a water source is safe for irrigation is most easily applied where many farmers draw water from a common source. Such a situation occurs on a formal irrigation scheme where water samples at the scheme intake can be monitored. It might also apply where the effluent from an existing treatment plant is to be used. Routine certification of water quality is much more difficult where many, very small-scale farmers act independently of each other and draw their water from numerous streams and shallow wells. To overcome this there would need to be clear market incentives and appropriate technical interventions to motivate small, independent farmers to come together in groups or associations for whom a single safe and monitored water source can be provided.

Where water certification is to be coupled with a formal labelling and crop certification programme there would be a need for farmers to work together in organisations that would bear responsibility for securing and maintaining certification of their water sources. It is clear that an intervention of this type – water certification and crop labelling – requires sustained activity by an independent agency in which consumers and producers can have confidence.

3.2.4 Crop restriction

For crop restriction to be effective Westcot (1997) suggests that all of the following conditions must apply:

- Irrigation using wastewater occurs only in well-defined sites (formal irrigation schemes) which have strong central management.
- Strong mechanisms to enforce the restriction regulations are in place and are respected.
- There is adequate demand and good prices for the crops permitted under the restrictions
- There is little market demand for excluded crops.

None of these conditions prevail and mandatory crop restriction is not a sensible option to pursue when attempting to improve the health of producers and consumers of informally irrigated produce in most African cities.

3.3 Simple interventions to address water quality

With the exception of evaluating / piloting the use of protected wells as a source of clean water, all of the foregoing interventions require policy decisions and actions to be taken on a large scale. Policy makers and government departments are therefore the focus of these interventions which would require a co-ordinated approach to be successful. The remaining interventions addressing water quality can be trialed or implemented on a smaller scale without the need for policy makers to be involved at the outset.

3.3.1 Alternative irrigation methods

Use of localised irrigation, which applies water to only a fraction of the field surface adjacent to the crop, with water delivered through a network of pipes, reduces the need for the irrigator to come into contact with polluted water. The crop will also be less exposed than when overhead irrigation by watering can or “sprinkler” is used. However, given the low levels of investment that most informal irrigators presently make in production inputs it is not clear if they would be able to invest in irrigation equipment of this type. When it is well managed, localised (drip) irrigation offers other potential advantages such as water saving and improved yields and these incentives might make the technology attractive, particularly where water is scarce or is carried manually over considerable distance.

A factor which must not be overlooked is that drip irrigation generally requires physically and chemically clean water to avoid clogging of the small dripper orifices. Some NGO’s and commercial manufacturers are currently evaluating low-cost or affordable drip irrigation technologies for smallholder farmers but it is too early to say whether they will be an appropriate technology for many informal urban and peri-urban irrigators.

Pressurised, piped, sprinkler irrigation again reduces the amount of contact that irrigators have with polluted water, when compared with surface irrigation or the use of watering cans or buckets. However, crops and thus consumers are still exposed to the same risks. Sprinkler irrigation could therefore only have a role in safer production where crop restriction was enforced, i.e. no irrigation of crops eaten raw.

3.3.2 Small-scale water treatment

Rose (1999) presents a review of community based technologies for domestic wastewater treatment. These include both on-site (household level) and off-site (neighbourhood level) systems. The former comprises various types of composting toilet and small-scale reedbed systems. The later includes larger constructed wetlands and use of various aquatic plant species and the more widely used waste stabilization ponds. All of these technologies seek to capture and treat domestic sewage before it enters rivers or other urban watercourses. After treatment the effluent may then be safely used for crop irrigation if land is available adjacent to the point of treatment. *These technologies can only have their effect on the quality of existing rivers and drains, which are presently used by irrigators, where they are adopted on a sufficiently wide-scale to significantly reduce the quantities of untreated waste entering rivers*.

Once pollutants have entered a river it is seldom practical to intervene to attempt to clean the whole river flow. Rather, reliance is placed on natural biological processes of oxidation and ultra violet effects to remove pathogens. This process may occur over many kilometres, the rate of rejuvenation being influenced by the flow rate and velocity, the amount of agitation that occurs over riffles or other falls and the permeability of the water to light.

To provide existing irrigators with a water source of improved quality some form of simple and low cost treatment must be available at the point of use, i.e. after water is abstracted from the water course and before application to the crop.

Actions such as short term retention of water in pools and the current practice of holding water in field side drums before applying it to the crop merit further evaluation to determine their effects on levels of pathogen die-off. Approaches such as these merit research and field evaluation with farmers, but actions must be low cost, or where this is not possible the farmer must be able to receive a premium for the financial and labour investments made in cleaning the water supply.

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