Guidelines for the safe use of wastewater in agriculture: revisiting WHO guidelines

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Abstract The use of wastewater in agriculture is occurring more frequently because of water scarcity and population growth. Often the poorest households rely on this resource for their livelihood and food security needs. However, there are negative health implications of this practice that need to be addressed. WHO developed Guidelines for the Safe Use of Wastewater in Agriculture in 1989. The Guidelines are currently being revised based on new data from epidemiological studies, quantitative microbial risk assessments and other relevant information. WHO guidelines must be practical and offer feasible risk management solutions that will minimize health threats and allow for the beneficial use of scarce resources. To achieve the greatest impact on health, guidelines should be implemented with other health measures such as: health education, hygiene promotion, provision of adequate drinking water and sanitation, and other health care measures.

Keywords Agriculture; guidelines; health protection; sanitation; wastewater use/reuse; WHO

Introduction The use of wastewater in agriculture is growing due to water scarcity, population growth and urbanization which lead to the generation of more wastewater in urban areas. Wastewater can be used to substitute for other better quality water sources, especially in agriculture. However, the uncontrolled use of wastewater in agriculture has important health implications for product consumers, farmers and their families, produce vendors, and communities in wastewater irrigated areas. Negative health impacts from the use of untreated or inadequately treated wastewater have been documented in many studies. Less attention has been paid to the positive health impacts of the use of wastewater in agriculture that may arise because of improved household food security, better nutrition and increased household income.

Guidelines for the Safe Use of Wastewater in Agriculture in agriculture need to maximize public health benefits and at the same time allow for the beneficial use of scarce resources. Achieving this balance in the variety of situations that occur worldwide (especially in settings where there may be no wastewater treatment) can be difficult. Guidelines need to be adaptable to the local social, economic and environmental conditions and should be co-implemented with other health interventions such as hygiene promotion, provision of adequate drinking water and sanitation, and other healthcare measures. It is important that health risks from the use of wastewater in agriculture be put into the context of the overall level of gastrointestinal disease within a given population as specified in the Stockholm Framework (see Bartram et al., 2001 for more information on the framework). Future WHO water-related guidelines will be developed in accordance with this framework.

The regulation of water quality for irrigation is of international importance because agricultural products grown with contaminated water may cause health effects at both the
local and international levels. International trade in agricultural products across regions is growing. Exports of contaminated fresh produce from different geographical regions can facilitate the spread of both known pathogens and strains with new virulence characteristics into areas where the pathogens are not normally found or have been absent for many years (Beuchat, 1998).

Effective guidelines for health protection should be practical and adaptable to local conditions, and include the following elements: (1) Evidence-based health risk assessment; (2) Guidance for managing risk (including options in addition to wastewater treatment); and (3) Strategies for guideline implementation (including progressive implementation where necessary). This paper provides an overview of the current wastewater use in agriculture situation, reviews the evidence concerning health impacts and outlines management steps that can be implemented to reduce potential health impacts – especially in low-resource situations.

Background
Worldwide, it is estimated that 18% of cropland is irrigated, producing 40% of all food (Gleick, 2000). A significant portion of irrigation water is wastewater. For example, Hussain et al. (2001) estimated that at least 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater. Smit and Nasr (1992) estimated that one tenth or more of the world's population consumes foods produced by irrigation with wastewater. Wastewater and excreta are also used in urban agriculture, which often supplies a large proportion of the fresh vegetables sold in many cities, particularly in less developed countries. For example in Dakar, Senegal, more than 60% of the vegetables consumed in the city are grown in urban areas using a mixture of groundwater and untreated wastewater (Faruqui et al., 2002).

In most developing countries, where wastewater is used for irrigation, it is commonly used without adequate treatment. For example, Homsi (2000) estimates that only around 10% of all wastewater in developing countries receives treatment. Given these circumstances, WHO guidelines must include feasible strategies for maximizing health protection when untreated wastewater is used in agriculture.

Health effects
In 2002, Blumenthal and Peasey completed a critical review of epidemiological evidence of the health effects of wastewater and excreta use in agriculture for WHO. This evidence was used as a basis for estimating threshold levels below which no excess infection in the exposed population could be expected. Further information on the risks of infection attributable to the exposure, and in particular the proportion of disease in the study population attributable to exposure (and therefore potentially preventable through improvement in wastewater quality), was used to inform proposals on appropriate microbiological guidelines for wastewater reuse in agriculture. The results of this epidemiological review are presented in Table 1.

Wastewater is often a resource for the poor and may have significant impacts on food security. Improving nutrition, especially for children, is very important for maintaining the overall health of individuals and communities. Improving the living standards of the poor through irrigation development (with wastewater or fresh water) may lead to better health (Van der Hoek et al., 2001).

Microbial guideline derivation
Worldwide many different microbial standards for wastewater use in agriculture have been developed. Most guidelines put heavy emphasis on microbial standards, but it should be recognized that other strategies for managing health risks can also be effective.
Table 1 Summary of health risks associated with the use of wastewater in irrigation

<table>
<thead>
<tr>
<th>Group exposed</th>
<th>Health threats</th>
<th>Bacteria/viruses</th>
<th>Protozoa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumers</td>
<td>Significant risks of <em>Ascaris</em> infection for both adults and children with untreated wastewater; no excess risk when wastewater treated to ≤1 nematode egg/litre except where conditions favour survival of eggs</td>
<td>Cholera, typhoid and shigellosis outbreaks reported from use of untreated wastewater; sero-positive responses for <em>Helicobacter pylori</em> (untreated); increase in non-specific diarrhoea when water quality exceeds 10^4 FC/100ml</td>
<td>Evidence of parasitic protozoa found on wastewater irrigated vegetable surfaces but no direct evidence of disease transmission</td>
</tr>
<tr>
<td>Farm workers and their families</td>
<td>Significant risks of <em>Ascaris</em> infection for both adults and children with contact with untreated wastewater; risks remain, especially for children when wastewater treated to &lt;1 nematode egg/litre; increased risk of hookworm infection to workers</td>
<td>Increased risk of diarrhoeal disease in young children with wastewater contact if water quality exceeds 10^4 FC/100 ml; elevated risk of <em>Salmonella</em> infection in children exposed to untreated wastewater; elevated seroresponse to <em>Norovirus</em> in adults exposed to partially treated wastewater</td>
<td>Risk of <em>Giardia intestinalis</em> infection was insignificant for contact with both untreated and treated wastewater, Increased risk of amoebiasis observed with contact with untreated wastewater</td>
</tr>
<tr>
<td>Nearby communities</td>
<td><em>Ascaris</em> transmission not studied for sprinkler irrigation but same as above for flood or furrow irrigation with heavy contact</td>
<td>Sprinkler irrigation with poor water quality 10^6–8 TC/100 ml, and high aerosol exposure associated with increased rates of infection; use of partially treated water 10^4–5 FC/100 ml or less in sprinkler irrigation is not associated with increased infection rates</td>
<td>No data for transmission of protozoan infections during sprinkler irrigation with wastewater</td>
</tr>
</tbody>
</table>

Sources: Blumenthal and Peasey (2002); Blumenthal et al. (2000a); Armon et al. (2002)

Blumenthal et al. (2000a) proposed revisions to the WHO microbiological guidelines for treated wastewater use in agriculture (Table 2). The main differences from the 1989 WHO guidelines are new recommendations for a faecal coliform (FC) value for restricted irrigation (≤10^5 FC/100 ml) and new faecal coliform and nematode egg limits in certain conditions when children are exposed.

**Risk management and decision making**

It is important to note that water quality requirements for the use of wastewater in unrestricted irrigation are often stricter than surface water quality requirements for unrestricted irrigation. Surface water in many places would not meet WHO faecal coliform guideline targets for unrestricted irrigation (UNEP, 1991) (although it is not always clear what level of risk this entails). Thus in some cases, strict wastewater quality standards for irrigation may paradoxically encourage the use of more contaminated water for irrigation resulting in greater health risks. For example, in irrigated areas near Santiago Chile, 60% of the river water used for irrigation contained in excess of 10,000 faecal coliforms per 100 ml (ten times the recommended WHO standard) (FAO, 1993). Additionally, the United States Environmental Protection Agency recommends a standard for irrigation with treated wastewater of ≤2.2 total coliforms per 100 ml, but when surface waters are used for irrigation a standard of ≤1,000 faecal coliform per 100 ml is required (USEPA, 1973).
Table 2 Recommended revised microbiological guidelines for treated wastewater use in agriculture*

<table>
<thead>
<tr>
<th>Category</th>
<th>Reuse conditions</th>
<th>Exposed group</th>
<th>Irrigation technique</th>
<th>Intestinal nematodes (arithmetic mean no of eggs per litre)</th>
<th>Faecal coliforms (geometric mean no per 100 ml)</th>
<th>Wastewater treatment expected to achieve required microbiological quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Unrestricted irrigation</td>
<td>Workers, consumers, public</td>
<td>Any</td>
<td>≤0.1 [≤1](^f)</td>
<td>≤ 10³</td>
<td>Well designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)</td>
</tr>
<tr>
<td>B</td>
<td>Restricted irrigation</td>
<td>(a) Spray/sprinkler</td>
<td>≤ 1</td>
<td>≤ 10⁵ [no standard]</td>
<td>Retention in WSP series inc. one maturation pond or in sequential WSTR or equivalent treatment (e.g. conventional secondary treatment supplemented by either polishing ponds or filtration) As for Category A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cereal crops, industrial crops, fodder crops, pasture and trees</td>
<td>(b) Flood/furrow</td>
<td>≤ 1</td>
<td>≤ 10³ [no standard]</td>
<td>As for Category A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1 Workers (but no children &lt;15 years), nearby communities</td>
<td>Any</td>
<td>≤0.1 [≤1](^f)</td>
<td>≤ 10³ [no standard]</td>
<td>As for Category A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B2 As B1</td>
<td>Trickle, drip or bubbler</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Pretreatment as required by the irrigation technology, but not less than primary sedimentation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B3 Workers including children &lt;15 years, nearby communities</td>
<td>None</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Localised irrigation of crops in category B if exposure of workers and the public does not occur</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: Adapted from Blumenthal et al. (2000a); WHO (1989)
* Values in brackets are the 1989 guideline values.
\(^a\) In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.
\(^b\) Ascaris and Trichuris species and hookworms; the guideline is also intended to protect against risks from parasitic protozoa.
\(^c\) During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve these egg numbers, then routine effluent quality monitoring is not required).
\(^d\) During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly).
\(^e\) A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
\(^f\) This guideline can be increased to ≤ 1 egg per litre if (i) conditions are hot and dry and surface irrigation is not used, or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater re-use.
\(^g\) In the case of fruit trees, irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used.
Chemical guidelines

It is difficult to assess the health impacts from toxic chemicals in wastewater used in irrigation because of the difficulty of associating chronic exposure of chemicals and chemical mixtures to diseases with long latency periods. However, health effects from both organic chemicals and heavy metals have been observed in some countries where industrial wastewater has been used for irrigation (Yuan, 1993; Chen, 1992; WHO, 1992).

In many countries, industrial wastewater is often mixed with municipal wastewater which is then used for irrigation. Industrial wastes may contain toxic organic and inorganic chemicals that can be taken up by the crops. The health risks associated with chemicals found in wastewater and sludge may need to be given more attention, particularly as industrialization increases in developing countries. To minimize adverse health and environmental effects from toxic substances, industrial wastes should be adequately pre-treated to remove these chemicals or should be treated separately from municipal wastewater and excreta. WHO is currently developing standards for a selection of harmful chemicals that might be found in wastewater. In many situations the safety of the wastewater for irrigation will need to be determined on a case-by-case basis, depending on the type of chemicals suspected to be present. Chemical analysis of the wastewater may be necessary.

Strategies for managing health risk

The protection of public health can best be achieved by using a “multiple barrier” approach that interrupts the flow of pathogens from the environment (wastewater, crops, soil etc.) to people. Human pathogens in the fields do not necessarily represent a health risk if other suitable health protection measures can be taken. These measures may prevent pathogens from reaching the worker or the crop or, by selection of appropriate crops (cotton for example), may prevent pathogens on the crop from affecting the consumer (Mara and Cairncross, 1989). The available measures for health protection can thus be grouped into five main categories: (1) Waste treatment, (2) Crop restriction, (3) Irrigation technique, (4) Human exposure control, and (5) Chemotherapy and vaccination.

It will often be desirable to apply a combination of several methods. Sometimes partial treatment to a less demanding standard may be sufficient if combined with other measures such as crop restriction but it may need to be supplemented by additional measures to protect agricultural workers.

Treatment

In the context of the use of municipal or domestic wastewater in agriculture, the removal or inactivation of excreted pathogens is the principal objective of wastewater treatment. Conventional wastewater treatment options (primary and secondary treatments), are often better at removing environmental pollutants (e.g., BOD) than pathogens. Many of these processes may be difficult and costly to operate properly in developing country situations due to their high energy, skilled labour, infrastructure and maintenance requirements (Carr and Strauss, 2001). In some cases, tertiary treatment (e.g., filtration and/or disinfection) will be required to reduce the concentrations of pathogens in the effluents to WHO recommended microbial guideline values.

There is a need for research and development work to improve the helminth egg removal efficacy of conventional systems to meet the microbial standards. Processes such as lime treatment, chemically enhanced primary treatment (CEPT), upward-flow anaerobic sludge blanket, sand filtration and storage in compartmentalized reservoirs deserve further study (Mara and Cairncross, 1989). In some situations, the quality of primary or secondary treated effluents can be improved by further treatment in a single polishing (maturation) pond of 5 days’ retention time (Mara and Cairncross, 1989). It may also be possible to consider
other options that improve microbial water quality, such as storage reservoirs to partially treat wastewater. For example, in Mexico, using wastewater from a series of wastewater reservoirs (as opposed to just one reservoir) mitigated the risks of diarrhoeal disease and *Ascaris* infections in farm workers and their families (Cifuentes *et al*., 2000). The use of reservoirs has the added advantage of being able to store and treat the wastewater for use in the dry season – often a time of peak demand.

**Crop restriction**
Crop restriction can be used to protect the health of consumers when water of sufficient quality is not available for unrestricted irrigation. For example, water of poorer quality can be used to irrigate non-vegetable crops such as cotton or crops that will be cooked before consumption (e.g., potatoes). However, crop restriction does not provide protection to the farm workers and their families where a low quality effluent is used in irrigation or where wastewater is used indirectly (i.e., through contaminated surface water) (Blumenthal *et al*., 2000b). Crop restriction is therefore not an adequate single control measure, but should be considered within an integrated system of control. Crop restriction has been used effectively in Mexico, Peru and Chile (Blumenthal *et al*., 2000b). In Chile the use of crop restriction when implemented with a general hygiene education program reduced the transmission of cholera from the consumption of raw vegetables by 90% (Monreal, 1993).

**Waste application methods**
Choosing a wastewater application method can impact health protection of farm workers, consumers, and nearby communities. Because of the formation of aerosols, spray/sprinkler irrigation has the highest potential to spread contamination on crop surfaces and affect nearby communities. Where spray/sprinkler irrigation is used with wastewater it may be necessary to set up a buffer zone (e.g., 50–100 metres from houses and roads) to prevent health impacts on local communities (Mara and Cairncross, 1989).

Farm workers and their families are at the highest risk when furrow or flood irrigation techniques are used. This is especially true when protective clothing is not worn and earth is moved by hand (Blumenthal *et al*., 2000b). Localized irrigation techniques (e.g., bubbler, drip, trickle) offer farm workers the most health protection because the wastewater is applied directly to the plants. Although these techniques are generally the most expensive to implement, drip irrigation has recently been adopted by some farmers in Cape Verde and India (FAO, 2001; Kay, 2001).

Vaz da Costa Vargas *et al.* (1996) has shown that cessation of irrigation for 1-2 weeks prior to harvest can be effective in reducing crop contamination. However, this is likely to be difficult in unregulated circumstances because many vegetables need watering nearly until harvest to increase their market value. However, this may be possible with some fodder crops that do not have to be harvested at the peak of their freshness (Blumenthal *et al*., 2000b).

**Human exposure control**
Four groups of people can be identified as being at potential risk from the agricultural use of wastewater. These are: Agricultural field workers and their families; Crop-handlers; Consumers (of crops, meat and milk), and Those living near the affected fields.

Agricultural field workers are at high risk of parasitic infections. Exposure to hookworm infection can be reduced, even eliminated, by the use of less-contaminating irrigation methods (as above) and by the use of appropriate protective clothing (i.e., shoes for field workers and gloves for crop handlers). A rigorous health education programme that targets consumers, farm workers, produce handlers and vendors is needed (Blumenthal *et al*.,
Hand washing with soap should be emphasized. Field workers should be provided with adequate water for drinking and hygiene purposes, in order to avoid the consumption of, and contact with, wastewater. Similarly, safe water should be provided at markets for washing and “freshening” produce. Consumers can cook vegetables, meat and milk, and practise good personal and domestic hygiene to protect their health. Meat should be inspected and carcasses infected with tapeworm larva should be rejected.

Chemotherapy and vaccination
Chemotherapy and immunisation cannot normally be considered as an adequate strategy to protect farm workers and their families exposed to raw wastewater or excreta. Immunisation against helminthic infections and most diarrhoeal diseases is currently not feasible. However, for highly exposed groups or sensitive subpopulations (e.g., tourists), immunisation against typhoid and hepatitis A may be worth considering. Chemotherapeutic control of intense nematode infections in children and control of anaemia in both children and adults, especially women and post-menarche girls is important. Chemotherapy must be reapplied at regular intervals to be effective – as many as 2–3 times a year for children living in endemic areas (Montresor et al., 2002).

Guideline implementation
Phased implementation of the WHO microbial water quality standards may be necessary as treatment is gradually introduced and improved over a period of time (e.g., 1–15 years). Implementation of the WHO guidelines for the safe use of wastewater and excreta in agriculture will protect public health the most when it is integrated into a comprehensive public health programme that includes other sanitary measures including personal and domestic hygiene education/outreach/behaviour change. For example, it may be possible to link health education and hygiene promotion to agricultural extension activities or other health programs (e.g., immunization programs) (Blumenthal et al., 2000b).

Conclusions
Developing realistic guidelines for using wastewater in agriculture involves the establishment of appropriate health-based targets prior to defining appropriate risk management strategies. Establishing appropriate health-based targets involves firstly the assessment of the risks associated with wastewater use in agriculture. Risks need to be put into the context of actual disease rates in a population related to all the exposures that lead to that disease, including other water- and sanitation-related exposures, as well as food-related exposure. Positive health impacts resulting from increased food security, improved nutrition, and additional household income should also be considered. Different countries may therefore set different health targets, based on their own contexts.

Strategies for managing health risks to achieve the health targets include wastewater treatment to achieve appropriate microbiological quality guidelines, crop restriction, waste application methods, control of human exposure, chemotherapy and vaccination. Phased implementation of the WHO microbial water quality standards may be necessary as treatment is gradually introduced and improved over a period of time (e.g., 1–15 years). For maximal public health effect, guidelines should be implemented as part of a package with other health promoting measures.

References


http://www.lboro.ac.uk/well/resources/well-studies/well-studies.htm.


