International guidelines for water recycling: microbiological considerations

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Abstract The World Health Organization and others have proposed international guidelines for the safe reuse of domestic wastewater. Treatment and microbial standards have been suggested with varying microbial water quality targets to suit local circumstances of affordability and health risks. However, it is important to recognize that universal application of bacterial standards for water quality assessment will not yield the same risks from microbial pathogens in reclaimed wastewater around the world. The concentration and types of pathogens in raw wastewater varies from one region of the world to another depending on the incidence in the community. This is influenced by the general hygiene, season, and per capita water use. Also, different treatment processes may be more effective in removing indicator bacteria and certain groups of pathogens than others. Proposed guidelines have also neglected the importance of water in the transmission of viral and bacterial diseases in developed countries and their impact on morbidity and mortality. Additional research is needed to better reduce the uncertainty of proposed guidelines for water recycling and to better define the risks associated to the exposed populations.

Keywords Effluent reuse; guidelines; international standards; microbial standards; pathogens; water recycling

Introduction Wastewater reuse or recycling of domestic wastewater is an essential part of water management in many regions of the developed and developing world. The wastewater may be recycled for industrial purposes (cooling towers), food or non-food crop irrigation, recreational waters (contact or non-contact), or as a supplement to potable supplies. Contained in domestic wastewater are a variety of disease causing bacteria, viruses, protozoa, and helminths that can be transmitted by ingestion and/or inhalation. The transmission of these agents by ingestion of contaminated food crops, swimming, and drinking water is well documented. Since some of these pathogenic microorganisms will always be present in untreated domestic wastewater they must be reduced to levels which minimize the risk to the population exposed to the recycled water. For this reason various water quality and treatment standards have been purposed depending on the intended reuse application.

The World Health Organization Guidelines were derived from the review of epidemiological studies of wastewater reuse, along with what was achievable by wastewater treatment processes (Havelaar et al., 2000). Studies were available on disease risk for some pathogens and illnesses on the risk of exposure to raw wastewater and excreta, and on the risk to farm workers in developing countries (Blumenthal et al., 2001). However, there was little data available on the effect of the use of treated wastewater to the general public, particularly in relation to consumption of vegetable crops. Where epidemiological evidence was not sufficient to allow the defining of a level (microbiological quality) at which no excess risk of infection would occur, data on pathogen removal by wastewater treatment processes, pathogen die-off in the field, and pervading guidelines for water quality were taken into account. These guidelines are shown in Table 1.
More recently a group of experts in the water recycling area have proposed international guidelines for recycled water based on draft Australian guidelines (Anderson et al., 2001). These guidelines, which are based on the level of FC and treatment received by the wastewater, are shown in Table 2.

### Limitations of current guidelines

Ideally, the objective of all guidelines is based upon a known risk of disease to the exposed population. The amount of risk (infection or illness) can be quantified by the route and level of exposure of a pathogen through quantitative microbial risk assessment (QRA) or thorough epidemiological studies. QRA requires knowledge of the level and type of pathogens to which an individual is exposed. Epidemiological studies require different sets of populations (ideally one exposed and the other not exposed) to determine the amount of risk caused by the additional exposure. Both approaches together can prove useful in the development of water quality and treatment guidelines. However, in the development of

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**Table 1** Recommended microbiological quality guidelines for wastewater use in agriculture (WHO, 1989)

<table>
<thead>
<tr>
<th>Cat</th>
<th>Reuse conditions</th>
<th>Exposed group</th>
<th>Intestinal nematodes²</th>
<th>FC (100 ml)³</th>
<th>Wastewater treatment expected to achieve required quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Irrigation of crops likely to be eaten uncooked, sports fields, public parks⁴</td>
<td>Workers, consumers public</td>
<td>≤ 1</td>
<td>≤1,000</td>
<td>A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment</td>
</tr>
<tr>
<td>B</td>
<td>Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees</td>
<td>Workers</td>
<td>≤ 1</td>
<td>None</td>
<td>Retention in stabilisation ponds for 8–10 days or equivalent helmith removal</td>
</tr>
<tr>
<td>C</td>
<td>Localised irrigation of crops if category B exposure of workers and the public does not occur</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Pre-treatment as required by the irrigation technology, but not less than primary sedimentation</td>
</tr>
</tbody>
</table>

¹ In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly
² Ascaris and Trichuris spp. and hookworms
³ During the irrigation period
⁴ A more stringent guideline ((200 FC/100 ml) is appropriate for public lawns with which the public may come into direct contact
⁵ In the case of fruit trees, irrigation should cease two weeks before the fruit is picked and none should be picked off the ground
⁶ Arithmetic mean
⁷ Geometric mean

More recently a group of experts in the water recycling area have proposed international guidelines for recycled water based on draft Australian guidelines (Anderson et al., 2001). These guidelines, which are based on the level of FC and treatment received by the wastewater, are shown in Table 2.

**Table 2** Possible recycled water grades and treatment an Australian suggestion (Anderson et al., 2001)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>FC/100 ml</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 star</td>
<td>Potable</td>
<td>≤ 1</td>
<td>Advanced multi-barrier treatment processes effective against microbiological and chemical pollutants</td>
</tr>
<tr>
<td>A+ 4 star</td>
<td>Open Access</td>
<td>&lt; 1</td>
<td>Secondary + membrane filtration + disinfection</td>
</tr>
<tr>
<td>A 3½ star</td>
<td>High Contact</td>
<td>&lt; 10</td>
<td>Secondary + filtration + disinfection</td>
</tr>
<tr>
<td>B 3 star</td>
<td>Medium Contact</td>
<td>&lt; 100</td>
<td>Secondary + disinfection</td>
</tr>
<tr>
<td>C 2 star</td>
<td>Low Contact</td>
<td>&lt; 1000</td>
<td>Secondary + disinfection (Advanced primary + filtration + disinfection)</td>
</tr>
<tr>
<td>D 1 star</td>
<td>Restricted Access</td>
<td>&lt; 10000</td>
<td>Secondary + maturation ponds Oxidation pond systems</td>
</tr>
</tbody>
</table>

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guidelines that may be applied on a worldwide basis it is important to recognize that use of bacterial indicators and level of treatment may not result in the same level of risk. Current suggested guidelines have not considered a number of important limitations in this approach which are listed in Table 3.

**Fecal coliforms as indicators of water quality and treatment performance**

Indicators such as FC may be used in a variety of ways as indicated in Table 4. In water recycling operations it is important to recognize that their principal use should be as a treatment performance measurement and as not as an indicator of virus or parasite presence, or risk.

FC bacteria (thermotolerant coliforms) have largely been developed and used as indicators of water quality in temperate climates and their use in tropical countries may be more limited. Evidence has accumulated that *E. coli* and FC are capable of growth and long term persistence in warm tropical waters (Fujoka *et al.*, 1999). While natural occurrence of these organisms may not be an issue during physical-chemical or activated sludge treatment they may interfere with an evaluation of performance of artificial wetlands, wastewater stabilization treatment processes or as the recycled water is being transported through open channels or pipes. Another issue with FC is that their removal by various treatment processes is not directly correlated with the removal of enteric pathogens (NRC, 1998). It is also important to recognize that there is not an established ratio of FC bacteria or other indicators with parasites and viruses in raw wastewater.

**Occurrence and Concentration of enteric pathogens in raw wastewater**

The occurrence and concentration of enteric pathogens in raw wastewater is dependent on a number of factors including the incidence of infection in the population, per capita water use, season, and social-economic status. The concentration of viral, protozoan parasites, and helminths in raw wastewater may be 10–1,000 greater in developed countries vs. developed countries (NRC, 1998; Buras, 1974; Martins *et al.*, 1983; Jimenez, 2002). This means that greater treatment will be required to achieve the same level of risk from exposure to recycled water in a developing country vs. a developed country. Although the rationale has been used that exposure from other sources (person-to-person spread) is greater in developing countries it still must be realized that recycled water treated to a level of 1,000 FC may have significantly more pathogens in it than recycled water treated in a

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**Table 3** Factors not considered in WHO guidelines for water recycling

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural occurrence of FC in tropical climates</td>
<td></td>
</tr>
<tr>
<td>Concentration of pathogens in the raw wastewater</td>
<td></td>
</tr>
<tr>
<td>Regional differences in the occurrence of enteric pathogens</td>
<td></td>
</tr>
<tr>
<td>Relative removal of FC and pathogens by treatment processes</td>
<td></td>
</tr>
<tr>
<td>Relative significance of different pathogens on human health and mortality</td>
<td></td>
</tr>
<tr>
<td>Limitations of existing epidemiological data</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4** Definitions for indicator and index micro-organisms of public health concern (Ashbolt *et al.*, 2001)

<table>
<thead>
<tr>
<th>Group</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process indicator</td>
<td>A group of organisms that demonstrates the efficacy of a process.</td>
</tr>
<tr>
<td>Faecal indicator</td>
<td>A group of organisms that indicates the presence of fecal contamination. They only infer that pathogens may be present.</td>
</tr>
<tr>
<td>Index and model organisms</td>
<td>A group/or species indicative of pathogen presence and behavior respectively, such as <em>E. coli</em> as an index for <em>Salmonella</em> spp. and F-RNA coliphages as models of human enteric viruses.</td>
</tr>
</tbody>
</table>
developed country. Reduction of trade barriers in the Americas has resulted in greater importation of food from developed countries and regulatory groups should be aware that food crops irrigated with recycled water meeting the proposed guidelines does not necessarily provide equal protection to all populations. Importation of food from developing countries has resulted in the introduction of enteric pathogens that are rare in the United States and other developed countries. The protozoan parasite *Cyclospora* spp. has caused numerous outbreaks of gastroenteritis in the United States and Canada due to the importation of contaminated raspberries (Katz *et al.*, 1999). Information is also lacking on the removal by treatment processes for many of these organisms e.g. hepatitis E virus, *Cyclospora* spp.

**Significance of different enteric pathogens on human health and mortality**
An aspect of the WHO guidelines is the inclusion of recommendations on the level of nematodes for use of recycled water to be used for crop irrigation (Table 1). Such a guideline was recommended because of the ease and low cost and training needed to identify and quantify nematode eggs, the high incidence of nematode infections in developing countries, epidemiological data showing a significant excess of intestinal nematode infections in farm workers and consumers of vegetable crops irrigated with untreated wastewater, and that food was a significant route of exposure for these infections (Havelaar *et al.*, 2001). It was also presumed that a lower relative risk of excess frequency of bacterial infections exists and a relatively small excess risk exists from viruses. However, these presumptions neglect the more serious nature of bacterial and viral infections, and new evidence on the importance of food and water in their transmission.

Nematode infections potentially transmitted by recycled water, such as trichuriasis, enterobiasis, ascaris, and hookworm, while common in the developing world do not have a major impact on mortality. While it is true that they impact the quality of life, most infections are asymptomatic and overt disease is rare in many cases (Mahmoud, 2000). In contrast, viral and bacterial gastroenteritis are a significant disease burden and second most common cause of mortality in developing countries (Pruss and Havelaar, 2001). In addition, while medical treatment is possible with nematode infections and bacterial infections, it is not available for enteric viral infections. Also the importance of food and water in the transmission of enteric viral infections should not be overlooked. Massive waterborne outbreaks of hepatitis E virus and rotavirus occur in developing countries in adults (Hung *et al.*, 1984; Naik *et al.*, 1992; Gerba *et al.*, 1997). A recent study in India on hepatitis E infections indicated that 70% of the cases were due to contaminated water and 20% due to food. Hepatitis E has a 2–3% mortality rate in the general population and up to 40% among pregnant women (Gerba *et al.*, 1996). Rotavirus infections may also be transmitted to adults by food (Sattar *et al.*, 2001; MMWR, 2000). Recent epidemiological studies have suggested more than half of all foodborne diseases in developed countries are due to caliciviruses (Inouye *et al.*, 2000; Deneen *et al.*, 2000).

**Conclusions and recommendations**
While the development of international guidelines is a laudable goal it must be realized that adaption of guidelines based solely on bacterial indicators and treatment requirements is not necessary reflective of the risks posed by the use of recycled water for different purposes. Without some type of microbial monitoring, treatment requirements cannot adequately be assessed for performance. While cost is often cited as a reason for the use of simple low cost indicators, it must be realized that there are severe limitations in their use to judge the performance of treatment operations and risks relative to waterborne enteric pathogens. One approach to reduce uncertainty is through the use of multiple indicators.
(i.e. coliphages, *Clostridium perfringens*) and a better understanding of the types, occurrence and concentration of pathogens in developing nations. These and other research needs to reduce the uncertainty of risks associated with water cycling are listed in Table 5. The more we understand the risks posed by water recycling from pathogens, the greater the confidence the public will have in its acceptance.

**References**


