QUANTIFYING HEALTH RISKS IN WASTEWATER IRRIGATION

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Summary

The guidelines developed by the World Health Organization for the safe use of wastewater in agriculture are based on a tolerable additional disease burden of 10^{-6} disability-adjusted life year loss per person per year, equivalent to rotavirus disease and infection risks of approximately 10^{-4} and 10^{-3} per person per year, respectively. The combination of standard quantitative microbial risk analysis techniques and 10,000-trial Monte Carlo risk simulations, using ranges of parameter values that reflect real life, are then used to determine the minimum required pathogen reductions for restricted and unrestricted irrigation which ensure that the risks are not exceeded. For unrestricted irrigation the required pathogen reduction is 6−7 $\log_{10}$ units and for restricted irrigation 3−4 $\log_{10}$ units. For both restricted and unrestricted irrigation wastewater treatment has to achieve a 3−4-$\log_{10}$ unit pathogen reduction, and in the case of unrestricted irrigation this has to be supplemented by a further 3−4-$\log_{10}$ unit pathogen reduction provided by post-treatment, but pre-ingestion, health protection control measures, such as pathogen die-off between the last irrigation and consumption (0.5−2 $\log_{10}$ unit reduction per day, depending on ambient temperature) and produce washing in clean water (1 $\log_{10}$ unit reduction). Wastewaters used for both restricted and unrestricted irrigation also have to contain no more than 1 human intestinal nematode egg per liter; if children under the

age of 15 are exposed then additional measures are required such as regular deworming at home or at school.

1. Introduction

In 1989 the World Health Organization (WHO) published guidelines for the microbiological quality of treated wastewaters used in agriculture for crop irrigation. The guidelines were: (a) for restricted irrigation (i.e., the irrigation of all crops except salad crops and vegetables that may be eaten uncooked), ≤1 human intestinal nematode egg l^{-1} (the nematodes are the human roundworm, *Ascaris lumbricoides*; the human whipworm, *Trichuris trichiura*; and the human hookworms, *Ancylostoma duodenale* and *Necator americanus*) (see *Helminth ova in wastewater and sludge intended for reuse in agriculture and aquaculture*); and (b) for unrestricted irrigation (i.e., including the irrigation of salad crops and vegetables eaten uncooked), the same nematode egg guideline and ≤1000 faecal coliforms (FC) per 100 ml. These guidelines caused considerable controversy since at the time of their introduction they had no rigorous epidemiological basis, and the FC guideline of ≤1000 per 100 ml was considered by some to be too lax, especially when compared with the Californian standard of ≤2.2 total coliforms per 100 ml.

New guidelines were published by WHO in 2006. These are based on a tolerable additional disease burden from working in wastewater-irrigated fields and consuming wastewater-irrigated crops of $\leq 10^{-6}$ DALY (disability-adjusted life year) loss per person per year (pppy) (see *Burden of disease: current situation and trends*). They thus differ markedly from the 1989 guidelines which were based solely on required wastewater qualities, but they have the same basis as the 2004 WHO drinking-water quality guidelines (this is reasonable since people expect the food they eat to be as safe as the water they drink). Although this tolerable DALY loss of $\leq 10^{-6}$ pppy is the fundamental basis of health protection in the guidelines for both drinking-water quality and wastewater use in agriculture, it has to be 'translated' into a tolerable risk of infection pppy as this is a metric that can be more easily used to derive wastewater qualities, as follows:

$$\text{Tolerable disease risk pppy} = \frac{\text{Tolerable DALY loss pppy (i.e., } 10^{-6})}{\text{DALY loss per case of disease}}$$

$$\text{Tolerable infection risk pppy} = \frac{\text{Tolerable disease risk pppy}}{\text{Disease/infection ratio}}$$

Tolerable disease and infection risks are determined for three 'index' pathogens: rotavirus (a viral pathogen), *Campylobacter* (a bacterial pathogen) and *Cryptosporidium* (a protozoan pathogen). Table 1 gives the DALY losses per case of rotavirus diarrhoea, campylobacteriosis and cryptosporidiosis, the tolerable risks of these diseases pppy for a tolerable DALY loss of 10^{-6} pppy, the disease/infection ratios and the resulting tolerable risks of infection with these pathogens pppy. From this table the following suitable 'design' risks are determined: a rotavirus disease risk of 10^{-4} pppy and a rotavirus infection risk of 10^{-3} pppy. These risks are very safe since the design rotavirus disease risk of 10^{-4} pppy is 3−4 orders of magnitude lower than the current global incidence of diarrhoeal disease of ~0.1−1 pppy.

Quantitative microbial risk analysis (QMRA) can then be used to determine appropriate wastewater qualities for various wastewater-use scenarios − for example restricted and unrestricted irrigation: with restricted irrigation the health of those working in wastewater-irrigated fields has to be protected, and with unrestricted irrigation it is the health of both those working in wastewater-irrigated fields and those consuming wastewater-irrigated crops eaten uncooked that has to be protected.

Pathogen	DALY loss per case of disease	Tolerable disease risk pppy equivalent to 10^{-6} DALY loss pppy	Disease/ infection ratio	Tolerable infection risk pppy
Rotavirus: (1) IC[a]	1.4×10^{-2}	7.1×10^{-5}	0.05	1.4×10^{-3}
(2) DC[a]	2.6×10^{-2}	3.8×10^{-5}	0.05	7.7×10^{-4}
Campylobacter	4.6×10^{-3}	2.2×10^{-4}	0.7	3.1×10^{-4}
Cryptosporidium	1.5×10^{-3}	6.7×10^{-4}	0.3	2.2×10^{-3}

[a] IC, industrialized countries; DC, developing countries.

Table 1. DALY losses, disease risks, disease/infection ratios and tolerable infection risks for rotavirus, *Campylobacter* and *Cryptosporidium*

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Biographical Sketch

Duncan Mara is a chartered civil engineer and a chartered biologist. He obtained his PhD from the University of Dundee, Scotland, in 1970 and was awarded the degree of DSc(Eng) by the University of Leeds, England, in 2001. He was a lecturer in public health engineering at the University of Nairobi, Kenya, during 1970−1973, and a senior lecturer in civil engineering at the University of Dundee during 1974−1979. He has been professor of civil engineering at the University of Leeds since 1979 and is currently a visiting professor of environmental engineering at the Universidad del Valle in Cali, Colombia. His research interests cover tropical sanitary microbiology, low-cost sanitation in developing countries, low-cost wastewater treatment in waste stabilization ponds, and health aspects of wastewater use in agriculture and aquaculture. He is the author/editor of 25 books and over 250 research papers.