4
Public health aspects

In developing countries excreta-related diseases are common, and excreta and wastewater contain correspondingly high concentrations of excreted pathogens. It is important to understand the transmission routes of these diseases and the health risk factors involved, in order to design and implement or modify excreta and wastewater use schemes that do not result in any increased transmission of these diseases.

4.1 Excreta-related infections

The infections in question are communicable diseases whose causative agents (pathogenic viruses, bacteria, protozoa and helminths) escape from the bodies of infected persons in their excreta, eventually reaching other people, whom they enter via either the mouth (for example when contaminated vegetables are eaten) or the skin (as in the case of hookworm and schistosomiasis). There are 30 known excreta-related infections of public health importance, and these may be conveniently grouped into five categories according to environmental transmission characteristics and pathogen properties (see Table 4.1).

Category I infections are caused by excreted viruses and protozoa and the helminths *Enterobius vermicularis* (pinworm or threadworm) and *Hymenolepis nana* (dwarf tapeworm). These pathogens are infective immediately on excretion ("non-latent") and have a low median infective dose. Transmission of these diseases occurs predominantly in the immediate domestic environment, especially when low standards of personal hygiene prevail, although survival times of excreted viruses and protozoa may be long enough to pose a health risk in excreta and wastewater use schemes (see Section 4.2).

The pathogens causing Category II infections are the excreted bacteria. Like the causative agents of Category I infections they are infective immediately on excretion. They are moderately persistent and can multiply outside their host, for example in food or milk. They are also very commonly transmitted in the immediate domestic environment, but their greater persistence means that they can

Table 4.1 Environmental classification of excreted infections

Category and epidemiological features	Infection	Environmental transmission focus	Major control measure
I. Non-latent; low infective dose	Amoebiasis Balantidiasis Enterobiasis Enteroviral infections Giardiasis Hymenolepiasis Hepatitis A Rotavirus infection	Personal Domestic	Domestic water supply Health education Improved housing Provision of toilets
II. Non-latent; medium or high infective dose; moderately persistent; able to multiply	*Campylobacter* infection Cholera Pathogenic *Escherichia coli* infection Salmonellosis Shigellosis Typhoid Yersiniosis	Personal Domestic Water Crop	Domestic water supply Health education Improved housing Provision of toilets Treatment of excreta before discharge or reuse
III. Latent and persistent; no intermediate host	Ascariasis Hookworm infection Strongyloidiasis Trichuriasis	Yard Field Crop	Provision of toilets Treatment of excreta before land application

IV. Latent and persistent; cow or pig as intermediate host	Taeniasis	Yard Field Fodder	Provisions of toilets Treatment of excreta before land application Cooking, meat inspection
V. Latent and persistent; aquatic intermediate hosts(s)	Clonorchiasis Diphyllobothriasis Fascioliasis Fasciolopsiasis Gastrodiscoidiasis Heterophyiasis Metagonimiasis Opisthorchiasis Paragonimiasis Schistosomiasis	Water	Provision of toilets Treatment of excreta before discharge Control of animal reservoirs Control of intermediate hosts Cooking of water plants and fish Reducing water contact

Source: Feachem et al. (1983).

survive longer transmission routes and therefore they can, and do, pose real health risks in excreta and wastewater use schemes. There are well documented cases of, for example, cholera epidemics caused by the irrigation of vegetable crops with untreated wastewater.

Infections of Categories III to V are caused by excreted helminths, which all require a period of time after excretion to become infective to humans. This period of latency occurs in soil, in water or in an intermediate host; most of the helminths are environmentally persistent, with survival times usually ranging from several weeks to several years. Excreta and wastewater use schemes are important mechanisms for transmission of many of these diseases, and a major environmental measure for their control is the effective treatment of excreta, wastewater and wastewater-derived sludges before use (see Section 7).

The diseases in Category III are caused by the soil-transmitted intestinal nematodes that require no intermediate host. The most important of these are the human roundworm (*Ascaris lumbricoides*), the hookworms (*Ancylostoma duodenale* and *Necator americanus*) and the human whipworm (*Trichuris trichiura*). They are all readily transmitted by the agricultural use of raw or insufficiently treated excreta and wastewater; indeed, of all excreted pathogens these cause the greatest public health concern in agricultural use schemes (see Section 4.3).

Category IV infections are caused by the cow and pig tapeworms, *Taenia saginata* and *T. solium*, respectively. For their successful transmission viable eggs must be ingested by a cow or pig; a potential route for the transmission of these diseases is the irrigation of pasture with wastewater.

The infections in Category V are all water-based helminthic infections. The pathogens require one or two intermediate aquatic hosts, the first of which is a snail, in which huge asexual multiplication of the pathogen occurs, and the second (if there is one) either a fish or an aquatic macrophyte. Many of these helminths have a limited geographical distribution (see Feachem et al., 1983), and it is only in endemic areas that their transmission is promoted by the aquacultural use of raw or insufficiently treated excreta and wastewater, together with the practice of eating raw or inadequately cooked fish and aquatic vegetables. Agricultural use is not relevant, except in so far as all irrigation schemes may facilitate the transmission of schistosomiasis.

4.2 Health risks

4.2.1 Actual and potential risks

For the agricultural or aquacultural use of excreta and wastewater to pose an *actual* risk to health requires *all* of the following to occur:

(a) *either* an infective dose of an excreted pathogen reaches the field or pond, *or* the pathogen multiplies in the field or pond to form an infective dose;

(b) the infective dose reaches a human host;

(c) the host becomes infected; and

(d) the infection causes disease or further transmission.

The risk remains a *potential* risk if only (a), or (a) and (b), or (a), (b) and (c) occur, but not (d).

Even if there is an actual risk involved, the agricultural or aquacultural use of excreta or wastewater will be of public health importance only if it causes a measurable excess incidence or prevalence of disease or intensity of infection. Epidemiological studies are needed to determine whether this is the case (see Section 4.3).

The sequence of events required for an actual health risk to be posed is summarized in Figure 4.1, together with the pathogen-host properties and interactions that influence each step in the sequence. If the sequence is broken at any point, the potential risks cannot combine to constitute an actual risk. This is the rationale behind the various methods of public health protection discussed in Section 7.

4.2.2. Risk factors

There is ample evidence (Feachem et al., 1983) that excreta and wastewater may—and, especially in developing countries, usually do—contain high concentrations of excreted pathogens, and that many of these pathogens can survive in these materials for some time and can also withstand most conventional treatment processes. They can thus arrive at the field or pond in large enough numbers for human infection to be theoretically possible. The only way that this can be prevented from happening is to remove or kill the pathogens before they reach the field or pond. However, even if sufficient pathogens do reach the field or pond, infection occurs only if an

Figure 4.1 Pathogen-host properties influencing the sequence of events between the presence of a pathogen in excreta or wastewater and measurable human disease attributable to excreta or wastewater use

EXCRETED LOAD

- latency
- multiplication
- persistence
- treatment survival

↓

INFECTIVE DOSE APPLIED TO LAND/WATER

- persistence
- intermediate host
- type of use practice
- type of human exposure

↓

INFECTIVE DOSE REACHES HUMAN HOST

- human behaviour
- pattern of human immunity

↓

RISKS OF INFECTION AND DISEASE

- alternative routes of transmission

↓

PUBLIC HEALTH IMPORTANCE OF EXCRETA AND WASTEWATER USE

From Blum & Feachem (1985), reproduced by permission of the International Reference Centre for Waste Disposal.

infective dose is received by a susceptible host, and this depends on the following factors (Blum & Feachem, 1985):

- the survival time of the pathogen in soil, on crops, in fish or in water;
- the presence, for Category IV and V infections, of the required intermediate host or hosts;
- the mode and frequency of excreta or wastewater application;

- the type of crop to which the excreta or wastewater is applied; and
- the nature of exposure of the human host to the contaminated soil, water, crop or fish.

Pathogen survival

The extensive literature on the survival times of excreted pathogens in soil and on crop surfaces has been reviewed by Feachem et al. (1983) and Strauss (1985). There are wide variations in reported survival times, which reflect both strain variation and differing climatic factors as well as different analytical techniques. None the less it is possible to summarize current knowledge on pathogen survival in soil and on crops in warm climates (20–30 °C) as shown in Table 4.2. Pathogen survival in excreta- and wastewater-enriched ponds is similar to that in waste stabilization ponds (see Section 7.2). Bacterial and viral numbers may be expected to decrease by only 1–3 orders of magnitude, depending on the available dilution, hydraulic retention time and climatic factors; helminth eggs and protozoal

Table 4.2. Survival times of selected excreted pathogens in soil and on crop surfaces at 20–30 °C

Pathogen	Survival time (days)	
	In soil	On crops
Viruses		
Enteroviruses[a]	< 100 but usually < 20	< 60 but usually < 15
Bacteria		
Faecal coliforms	< 70 but usually < 20	< 30 but usually < 15
Salmonella spp.	< 70 but usually < 20	< 30 but usually < 15
Vibrio cholerae	< 20 but usually < 10	< 5 but usually < 2
Protozoa		
Entamoeba histolytica cysts	< 20 but usually < 10	< 10 but usually < 2
Helminths		
Ascaris lumbricoides eggs	Many months	< 60 but usually < 30
Hookworm larvae	< 90 but usually < 30	< 30 but usually < 10
Taenia saginata eggs	Many months	< 60 but usually < 30
Trichuris trichiura eggs	Many months	< 60 but usually < 30

[a] Includes poliovirus, echovirus, and coxsackievirus.

From Feachem et al. (1983), reproduced by permission of the World Bank.

cysts will settle to the bottom of the pond where they may remain viable for a long time.

The available evidence indicates that almost all excreted pathogens can survive in soil and ponds for a sufficient length of time to pose potential risks to farm and pond workers (see Figure 4.2). Pathogen survival on crop surfaces is much shorter than that in soil, as the pathogens are less well protected from the harsh effects of sunlight and desiccation. In some cases, however, survival times can be long enough to pose potential risks to crop handlers and consumers, especially when they exceed the length of crop (mainly vegetable) growing cycles (Figure 4.3). The situation is similar for those who handle and consume fish and aquatic macrophytes.

Intermediate hosts

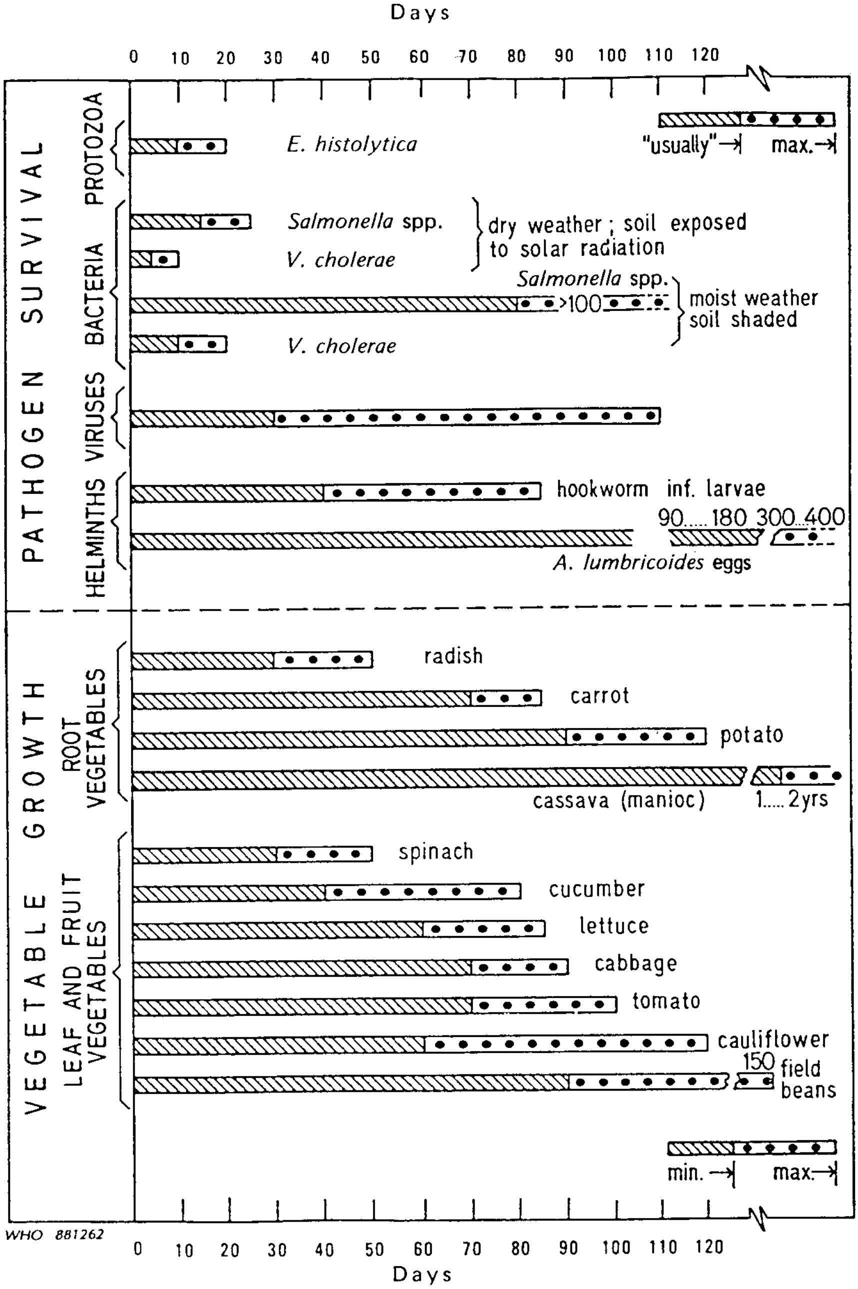
Irrigation of pasture with wastewater that contains viable *Taenia saginata* eggs will induce bovine cysticercosis only if cows have access to the pasture while the eggs are still viable. An interval of at least 14 days between irrigation and grazing is therefore recommended and, in some countries, obligatory. Education of farmers and enforcement of regulations are necessary additional control measures. In the case of pig tapeworm, pigs become infected in practice only if they have direct access to human faeces (which they readily consume), and excreta fertilization and wastewater irrigation of crops do not generally promote any significant disease transmission.

In the case of Category V infections, the secondary intermediate aquatic host—a fish or aquatic plant—is the desired aquacultural product, and infection occurs only if a viable egg reaches the pond, if there are suitable snail hosts in the pond and if the secondary host is eaten raw or insufficiently cooked. These "aquacultural diseases" occur only in certain restricted geographical areas of Asia, where these three factors are all present (see Section 4.4.3).

Mode and frequency of application

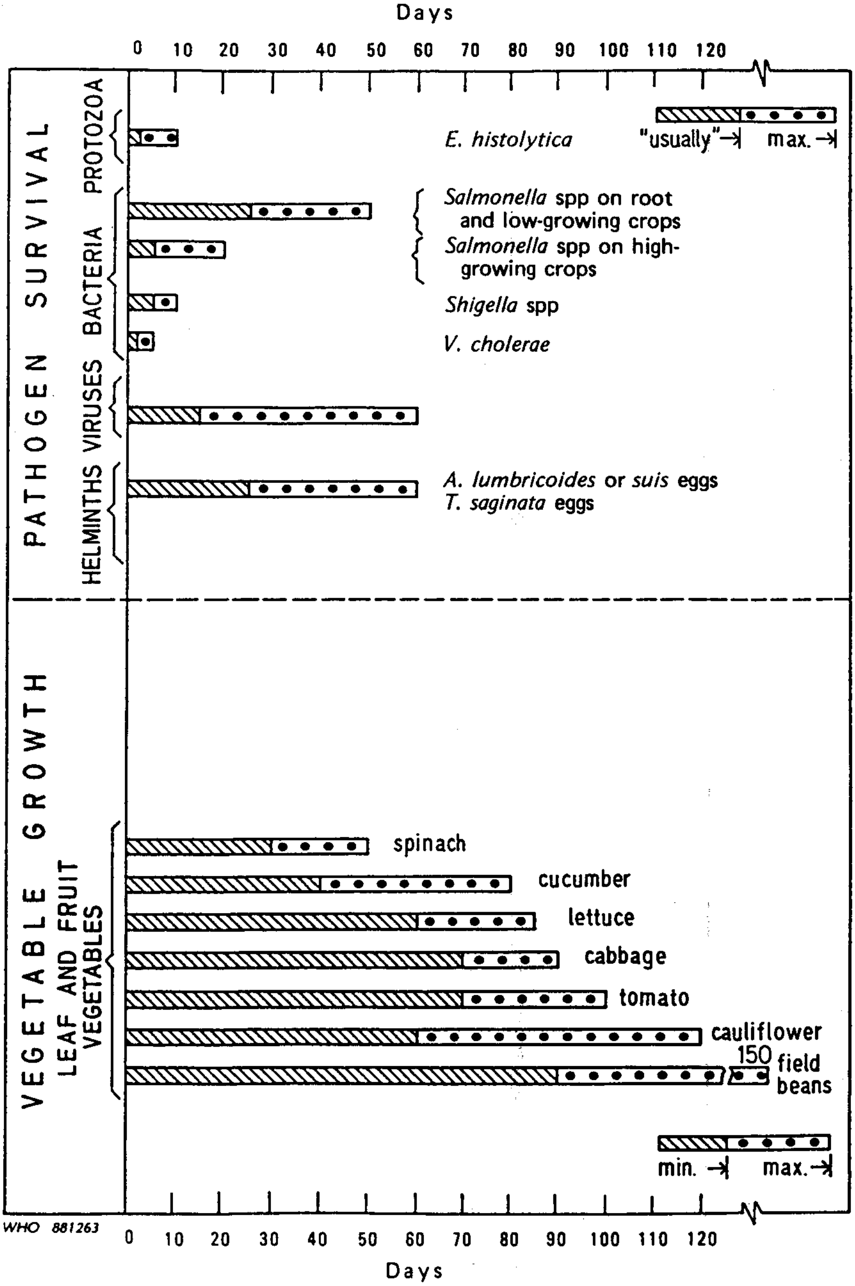
The way in which excreta or wastewater is applied to the land or pond, the interval between successive applications and the interval between the last application and harvesting all affect the likely degree of crop contamination and the environmental dispersion of excreted pathogens. Strategies to minimize these effects are discussed in Section 7.4.

Figure 4.2 Pathogen survival in soil compared with vegetable growth periods in warm climates



Reproduced by permission from Strauss (1985).

Figure 4.3 Pathogen survival on crops compared with vegetable growth periods in warm climates



Reproduced by permission from Strauss (1985).

Type of crop and type of exposure

The production of agricultural and aquacultural crops intended for human consumption poses potential risks to farm or pond workers, to those who handle the products and to those who consume them. If the products are fodder crops, farm workers and those who consume the resulting meat or milk are at potential risk; in the case of industrial products (for example, sugar-beet, fishmeal) only farm or pond workers and product handlers are subjected to risk. In the case of sprinkler irrigation, people living near the irrigated fields, who are at potential risk from pathogens present in wind-dispersed aerosol droplets, form an additional exposure group.

The greatest risk is associated with crops eaten raw, for example salad crops, especially if they are root crops (such as radishes) or grow close to the soil (for instance, lettuces). Pathogen survival times can be greater than the crop growing time, so that contamination is highly likely unless the excreta or wastewater is treated to a very high standard (see Section 7.2).

Host immunity

Significant host immunity occurs only with the viral diseases and some bacterial diseases (for example typhoid). The role of immunity is most noticeable in the case of viral infections where infection at an early age is very common (even in communities with high standards of personal hygiene), with the result that the adult population is largely immune to the disease and frequently also to infection.

Human behaviour

Adequate standards of personal and food hygiene and, in the case of occupational exposure, the wearing of protective clothing and footwear can protect against infection even in situations where the risk of infection would otherwise be extremely high. Health education is needed to alter certain behavioural patterns. However, this is a long-term solution and may not be at all effective in modifying certain cultural preferences, for example the eating of raw fish. Sociocultural aspects of excreta and wastewater use are discussed further in Section 5.

Alternative routes of pathogen transmission

The factors outlined above determine the potential health risks associated with excreta and wastewater use. The relative importance of such risks depends on the existence of any alternative routes by which the excreted pathogens reach those at risk. If there are many such alternative routes, excreta and wastewater use may not pose a significant additional risk. Conversely, if there are no such routes, excreta and wastewater use is entirely responsible for the risk induced.

These two situations may be illustrated by considering the inhabitants of a wealthy, modern city and those of a poor, traditional village who both consume vegetables fertilized with the villagers' excreta. Let us suppose that the standards of personal and environmental hygiene are very high in the city, but very low in the village. Then the only (or almost the only) exposure of the city inhabitants to excreted pathogens is via the vegetables. For the villagers, however, this transmission route will be only one of many, and not necessarily the most important, since the high level of faecal contamination of their immediate environment is likely to give rise to much more direct exposure and consequent infection and disease. Thus, preventing consumption of the vegetables in the city would be an effective control strategy, but similar measures in the village would probably have little if any effect on the disease transmission rate.

4.3 Epidemiological evidence

The actual public health importance of excreta or wastewater use can be assessed only by determining whether it results in an incidence, prevalence or intensity of disease measurably in excess of that which occurs in its absence. If it does not, its public health importance is negligible. On the other hand, if it does, the magnitude of its importance will depend upon the balance between the public health significance of the measured excess incidence, prevalence or intensity and its public health benefits. Benefits may include improved community nutrition resulting from increased food consumption, for instance.

An epidemiological study is required to determine whether excreta or wastewater use in a particular context results in a measurable excess incidence, prevalence or intensity of disease. Such studies are methodologically difficult but have no substitute if actual—as opposed to potential—health risks are to be assessed. Despite the fact that there have been relatively few well designed epidemiological studies on excreta and wastewater use, it is possible to draw certain conclusions from the evidence currently available. This is easiest in the case of wastewater irrigation, for which the evidence is greatest;

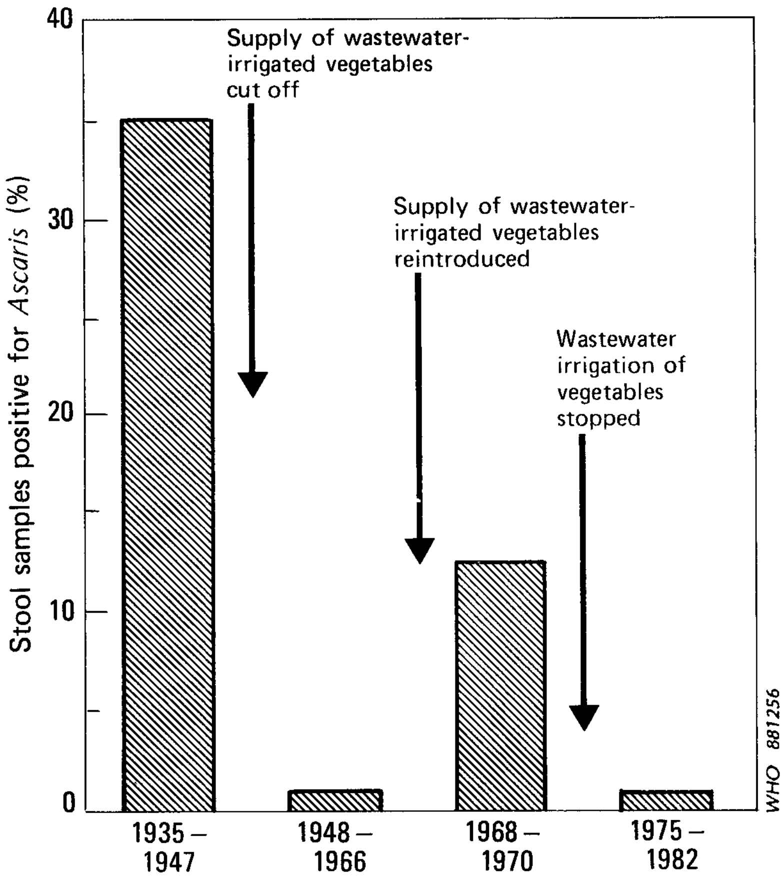
there is much less information about agricultural use of excreta and aquacultural use of wastewater and excreta.

4.3.1 Agricultural use of wastewater

Shuval et al. (1986) have rigorously reviewed all the available epidemiological studies conducted on the agricultural use of wastewater. Their principal conclusions can be summarized as follows:

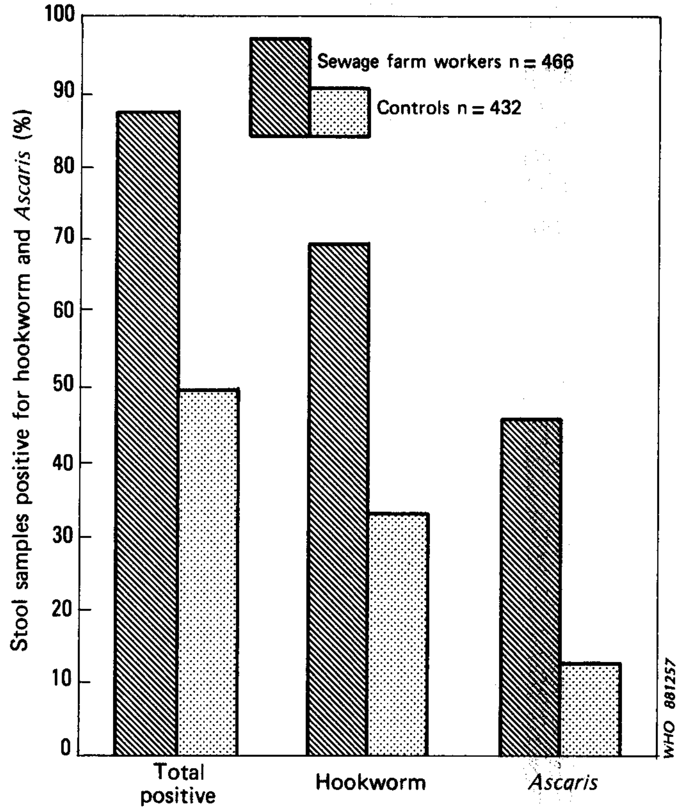
- Crop irrigation with untreated wastewater causes significant excess infection with intestinal nematodes in both consumers (Figure 4.4) and farm workers (Figure 4.5); the latter, especially if

Figure 4.4 Relationship between *Ascaris*-positive stool samples in the population of western Jerusalem and the availability of vegetables and salad crops irrigated with raw wastewater in Jerusalem, 1935–1982



From Shuval et al. (1986), reproduced by permission of the World Bank.

Figure 4.5 Prevalence of hookworm and *Ascaris* infections in sewage farm workers and control groups in various regions of India



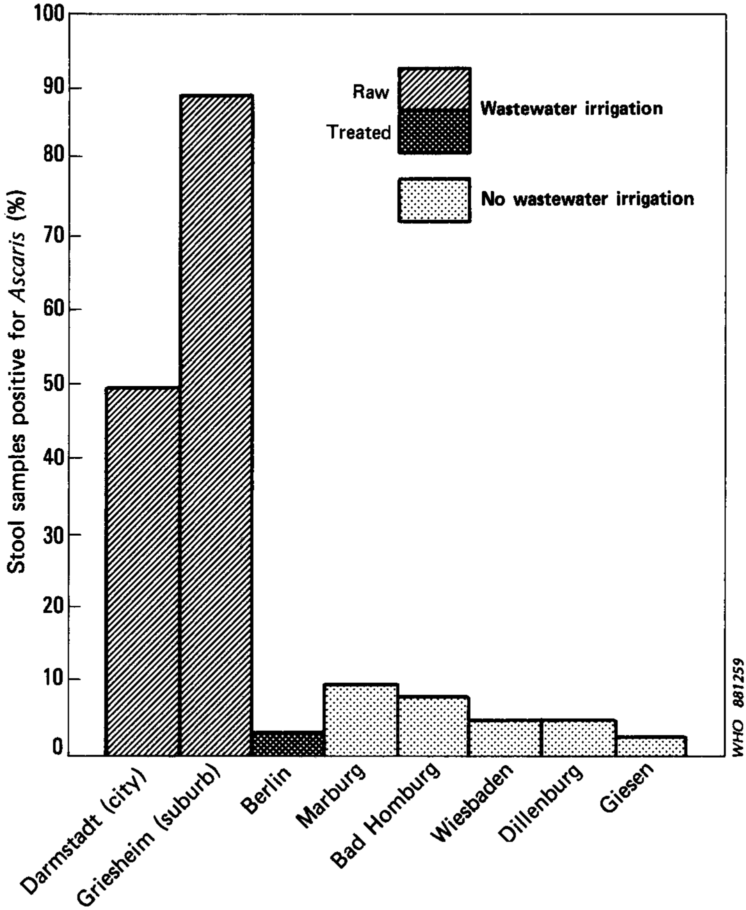
From Shuval et al. (1986), reproduced by permission of the World Bank.

they work barefoot in the fields, are likely to have more intense infections, particularly of hookworms, than those not working in wastewater-irrigated fields.

- Crop irrigation with treated wastewater[1] does not lead to excess intestinal nematode infection among field workers or consumers (Figure 4.6).
- Cholera, and probably also typhoid, can be effectively transmitted by the irrigation of vegetables with untreated wastewater (see Box 4.1).

[1] "Treated wastewater" here refers to conventional treatment, that is primary sedimentation, biological treatment (trickling filters or activated sludge) and secondary sedimentation. Conventional effluents contain few helminth ova or protozoan cysts but have high concentrations of faecal bacteria and viruses (see Section 7).

Figure 4.6 Wastewater irrigation of vegetables and ascariasis prevalence in Berlin (West) and a number of cities in the Federal Republic of Germany in 1949



Raw wastewater was used for irrigation in Darmstadt and conventionally treated wastewater (primary sedimentation, biofiltration and secondary sedimentation) in Berlin (West).

From Shuval et al. (1986), reproduced by permission of the World Bank.

- Cattle grazing on pasture irrigated with raw wastewater may become infected with *Cysticercus bovis* (the larval stage of the beef tapeworm *Taenia saginata*), but there is little evidence for actual risk of human infection.

- There is limited evidence that the health of people living near fields irrigated with raw wastewater may be negatively affected, either directly by contact with the soil or indirectly through

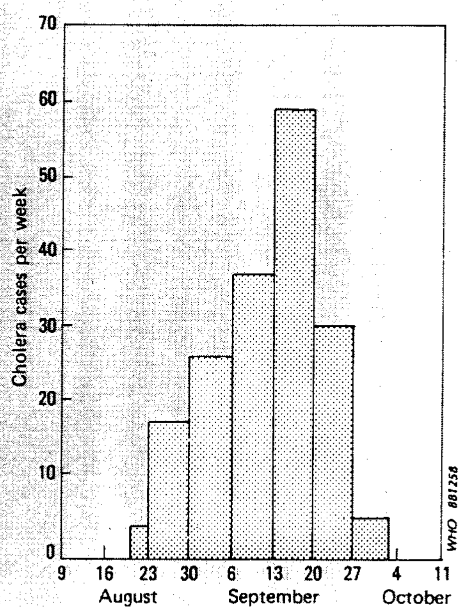
Box 4.1 The 1970 Jerusalem cholera epidemic

The cholera epidemic that occurred in Jerusalem in August and September 1970 was the first occasion on which credible epidemiological evidence was obtained for the transmission of an excreted bacterial infection by wastewater-irrigated vegetables.

In the summer of 1970 numerous cases of cholera were reported in the countries adjacent to Israel. Three cases of cholera appeared in Jerusalem on August 20. The outbreak reached a peak of 59 cases in the week of September 13–19. All known acute cases were investigated in detail: there was little evidence of secondary contact — no infections were found in family groups or among co-workers — and there was no spread to other Israeli cities, even though Jerusalem remained open for normal commerce and tourism. It thus appeared that a common-source epidemic was occurring.

Routine bacteriological monitoring of the city's water supply indicated zero coliform counts; all milk and dairy products were pasteurized under strict laboratory quality control; general sanitation within the city was high — there were few or no exposed excreta and a low housefly population.

The most likely common source appeared to be the salad crops and vegetables grown in the Kidron and Refaim valleys adjacent to the city, where fields were irrigated with the city's raw wastewater.



Weekly distribution of cholera cases in Jerusalem, August–September 1970 ($n = 176$). Irrigation of vegetables and salad crops with raw wastewater was stopped by the authorities during the week beginning September 13.

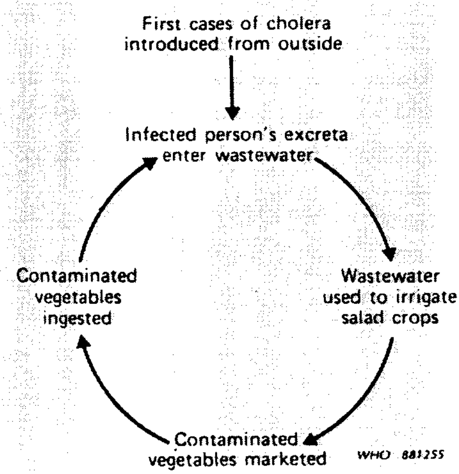
(Box 4.1 continued)

Their purchase was often mentioned by those who contracted the disease, and in several cases the only family member who became ill was the one who had consumed these products.

An intensive programme of sampling and testing for *Vibrio cholerae* in the wastewater in the city's main outfall sewers, in the soil on the wastewater-irrigated fields and on vegetables growing there and on sale in local markets was initiated. During the epidemic 18% of wastewater samples were positive for *V. cholerae*, and serological examination showed that the *V. cholerae* isolates were the same serotype as that found in the vast majority of the clinical cases; no *V. cholerae* were found in wastewater after the epidemic. Cholera vibrios and phages were also detected in the wastewater-irrigated soil and on vegetables grown there and on sale in local markets. Subsequent laboratory studies showed that *V. cholerae* could survive in wastewater, on soil and on crop surfaces for long enough to make this mode of transmission possible.

The Israeli health authorities ordered the cessation of the growing and marketing of wastewater-irrigated crops; harvested crops were confiscated and those still growing destroyed during September 15–20. The epidemic rapidly subsided and the last clinical case was detected some 12 days later.

It is now clear that the 1970 cholera epidemic in Jerusalem was initiated by imported clinical or subclinical cases, and that the main pathway for the secondary spread of the disease was through wastewater-irrigated vegetables.



Hypothesized cycle of transmission of *Vibrio cholerae* from first cholera cases or carriers introduced from outside Jerusalem, through wastewater-irrigated vegetables, back to residents in the city.

Source: Shuval et al. (1986)

contact with farm labourers. In communities with high standards of personal hygiene such negative impacts are usually restricted to an excess incidence of benign gastroenteritis, often of viral etiology, although there may also be an excess of bacterial infections.

- Sprinkler irrigation with treated wastewater[1] may promote the aerosol transmission of excreted viruses, but disease transmission is likely to be rare in practice since most people have high levels of immunity to the viral diseases endemic in their community.

From these findings it is clear that, when untreated wastewater is used for crop irrigation, intestinal nematodes and bacteria present high actual risk and the viruses little or no actual risk (see Table 4.3). The actual risks of protozoal infection are not yet well established—insufficient epidemiological data are available—but no study has shown that waste reuse causes additional risk. It is also clear that treatment of wastewater is a very effective method of safeguarding public health.

4.3.2 Agricultural use of excreta

Blum & Feachem (1985) have extensively reviewed the existing epidemiological literature on the transmission of disease associated with the fertilization of crops with excreta. Many of the studies reviewed are from China and Japan where this practice is, or was, common. Their conclusions are very similar to those of Shuval et al. (1986) for crop irrigation, and can be summarized as follows:

- Crop fertilization with raw excreta causes excess infection with intestinal nematodes in both consumers and field workers.

- There is evidence that excreta treatment reduces the transmission of nematode infection.

- The fertilization of rice paddies with excreta may lead to excess schistosomiasis infection among rice farmers.

[1] "Treated wastewater" here refers to conventional treatment, that is primary sedimentation, biological treatment (trickling filters or activated sludge) and secondary sedimentation. Conventional effluents contain few helminth ova or protozoan cysts but have high concentrations of faecal bacteria and viruses (see Section 7).

Table 4.3 Relative health risks from use of untreated excreta and wastewater in agriculture and aquaculture

Class of pathogen	Relative excess frequency of infection or disease
Intestinal nematodes: *Ascaris* *Trichuris* *Ancylostoma* *Necator*	High
Bacterial infections: bacterial diarrhoeas (e.g. cholera, typhoid)	Lower
Viral infections: viral diarrhoeas hepatitis A	Least
Trematode and cestode infections: schistosomiasis clonorchiasis taeniasis	From high to nil, depending upon the particular excreta use practice and local circumstances

- Cattle may become infected with *Cysticercus bovis* but are unlikely to contract salmonellosis.

4.3.3 Aquacultural use

Three potential health risks are associated with the aquacultural use of excreta and wastewater (Feachem et al., 1983):

- passive transference of excreted pathogens by fish and cultured aquatic macrophytes;
- transmission of trematodes whose life cycles involve fish and aquatic macrophytes (principally *Clonorchis sinensis* and *Fasciolopsis buski*); and
- transmission of schistosomiasis.

Blum & Feachem (1985) also reviewed the available epidemiological studies on excreta use in aquaculture. They found only one study that considered actual health risks associated with the passive transference of excreted pathogens, and the results of this were inconclusive because of the epidemiological methodology employed. They found none dealing with occupational exposure leading to schistosomiasis. With respect to trematode infections they found that fertilization of ponds with excreta was important in the transmission of these diseases but that so too was incidental faecal pollution of other local water bodies and ponds not purposefully fertilized with excreta.

4.4 Microbiological quality criteria

The epidemiological evidence briefly reviewed above clearly indicates that certain current excreta and wastewater use practices can result in actual health risks to certain exposure groups (for example, nematode and bacterial infections). In some cases (viral disease transmission by wastewater irrigation) the evidence indicates that there is no risk of excess disease and in others (bacterial disease risks in aquacultural use) no unequivocal evidence is available. The existing epidemiological data base needs of course to be improved. Despite its limitations, however, it can be usefully combined with a realistic appraisal of potential health risks to provide a reasonable basis for the development of microbiological quality criteria for treated excreta and wastewater intended for agricultural and aquacultural use.

The engineer who designs an excreta or wastewater treatment plant needs to know the extent to which excreted pathogens must be removed. The strict epidemiological answer is that the degree of treatment required is that which prevents excess disease transmission. This is not a helpful answer, however, because of the considerable uncertainty over minimal infective doses of many of the excreted pathogens, and because treatment efficiency is determined not by the residual concentration of pathogens (or pathogen indicators) in the treated wastes, but by the proportion removed. None the less, the design engineer needs a treatment product standard expressed in terms of the maximum permissible concentration(s) of specified organisms for each excreta and wastewater use practice. Microbiological quality criteria have been promulgated in several countries for wastewater intended for crop irrigation, but no criteria have yet been established for the quality of excreta used for crop fertilization or of excreta or wastewater for aquacultural use.

4.4.1 Wastewater quality for agricultural use

Historically, criteria[1] for the quality of wastewater for crop irrigation have been developed by borrowing from the water supply industry the concept of faecal indicator organisms. Coliform bacteria have long been used for this purpose and, while others exist, coliforms are still the indicator organism most commonly used despite the fact that not all of them are exclusively faecal. Non-faecal strains are of no use in assessing faecal pollution, and only the "faecal coliforms", which are indeed exclusively faecal in origin, can be used for this purpose. The term "total coliforms" is used to refer to an undifferentiated population of faecal and non-faecal types.

Wastewater quality guidelines and standards[1] are thus often expressed in terms of maximum permissible concentrations of total and/or faecal coliform bacteria. Since the faecal origin of wastewater is not in question, the implication is that these faecal indicator organisms can be used as pathogen indicators, and that there is at least a semiquantitative relationship between pathogen and indicator concentrations. In practice faecal coliforms can be used as reasonably reliable indicators of bacterial pathogens, as their environmental survival characteristics and rates of removal or die-off in treatment processes are broadly similar. Total coliforms are less reliable since, in warm climates especially, the proportion of non-faecal coliforms is often very high. Faecal coliforms are less effective as indicators of excreted viruses, and of very limited use for protozoa and helminths for which no reliable indicators exist.

Standards or guidelines for wastewater quality for crop irrigation generally specify both explicit standards (for example maximum coliform concentrations) and minimum treatment requirements (primary, secondary or tertiary) according to the class of crop to be irrigated (consumable, non-consumable). Standards developed 10–20 years ago tend to be very strict, as they were based on an evaluation of potential health risks associated with pathogen survival in wastewater, in soil and on crops, and on technical feasibility. The technology of choice for pathogen removal at that time (as judged by coliform removal) was effluent chlorination and, since this could easily achieve very low residual coliform concentrations, the maximum permissible coliform concentration was set correspondingly

[1] The scientific community develops, on the basis of the evidence available, quality *criteria*. These are used by such agencies as FAO and WHO to develop quality *guidelines*. These in turn can be used by governments to establish quality *standards* that can be enforced through laws and regulations in the country concerned.

low. For example, the 1968 California standards permit only 23 or 2.3 total coliforms per 100 ml, depending on the crop being irrigated (California State Department of Public Health, 1968); in 1973 a WHO Meeting of Experts noted that it was "technically feasible under field conditions to produce a sewage effluent containing not more than 100 coliform organisms per 100 ml" and that unrestricted irrigation of agricultural crops with such effluent was likely to produce only "a limited health risk" (World Health Organization, 1973). However, there is a wide variation in standards for wastewater use, as shown in Table 4.4.

Table 4.4 Examples of current microbiological standards for wastewater used for crop irrigation

Country	Restricted irrigation	Unrestricted irrigation
Oman	Maximum 23 TC/100 ml[a] Average < 2.2 TC/100 ml Greenbelt irrigation only	Crop irrigation not permitted
Kuwait	< 10 000 TC/100 ml	< 100 TC/100 ml Not salad crops or strawberries
Saudi Arabia	Use of secondary effluent permitted for forage crops, field crops and vegetables which are processed and also for landscape irrigation	< 2.2 TC/100 ml < 50 FC/100 ml[b]
Tunisia	Fruit trees, forage crops and vegetables eaten cooked: — secondary treatment (including chlorination) — absence of *Vibrio cholerae* and salmonellae	No irrigation of vegetables eaten raw
Mexico	For recreational areas: < 10 000 TC/100 ml < 2 000 FC/100 ml	For vegetables eaten raw and fruits with possible soil contact: < 1000 TC/100 ml
Peru	Treatment specified depending on reuse option	No irrigation of low-growing and root crops that may be eaten raw

[a]TC: total coliforms
[b]FC: faecal coliforms

Reproduced by permission from Strauss (1987).

Evaluation of the credible epidemiological evidence — that is, an appraisal of the actual, as opposed to potential, health risks (Section 4.3) — indicates that these standards may be unjustifiably restrictive. Moreover, design methods for waste stabilization ponds, which are generally the wastewater treatment system of first choice in developing countries (see Section 7.2), have been refined considerably during the past 10–20 years, so that any required level of pathogen removal can now be readily achieved with a very high degree of confidence. As a result of these considerations, a Meeting of Experts sponsored by the World Bank, the World Health Organization and the International Reference Centre for Waste Disposal (IRCWD) and held in Engelberg, Switzerland, in July 1985, recommended the guidelines shown in Table 4.5. A detailed explanation of the rationale for the "Engelberg" quality guidelines is given in Box 4.2 as the "Adelboden Statement."

Table 4.5 Tentative microbiological quality guidelines for treated wastewater reuse in agricultural irrigation

Note: In specific cases, the guidelines should be modified according to local epidemiological, sociocultural, and hydrogeological factors.

Reuse process	Intestinal nematodes[a] (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Restricted irrigation[b]		
Irrigation of trees, industrial crops, fodder crops, fruit trees[c] and pasture[d]	⩽ 1	not applicable
Unrestricted irrigation		
Irrigation of edible crops, sports fields, and public parks[e]	⩽ 1	⩽ 1000[f]

[a] *Ascaris, Trichuris* and hookworms.
[b] A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond or its equivalent is required in all cases.
[c] Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.
[d] Irrigation should cease two weeks before animals are allowed to graze.
[e] Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas.
[f] When edible crops are always consumed well cooked, this recommendation may be less stringent.

Source: International Reference Centre for Waste Disposal (1985)

The Engelberg quality guidelines for restricted irrigation (trees, industrial and fodder crops, fruit trees and pasture) introduced for the first time an explicit helminth standard (<1 viable intestinal nematode egg per litre), which implies a very high degree of egg removal (>99%). Its purpose is to protect the health of agricultural workers, who are at high risk from intestinal nematode infection. Wastewater complying with this guideline will contain few, if any, protozoan cysts so that field workers and consumers will also be protected from protozoal infections. Similarly, the wastewater will contain no (or, exceptionally, very few) *Taenia* eggs, so that grazing cattle will be protected from *Cysticercus bovis* and thus consumers also from beef tapeworm infection. There are several treatment options to achieve this quality, but the most appropriate in many cases will be a waste stabilization pond system comprising a 1–2-day anaerobic pond followed by a facultative pond and a maturation pond, each with a retention time of at least 5 days (Mara & Silva, 1986).

The Engelberg quality guideline for unrestricted irrigation (edible crops, including those eaten raw, sports fields, public parks) comprises the same helminth requirement and a maximum geometric mean concentration of 1000 faecal coliforms per 100 ml. The purpose of this latter recommendation is to protect the health of the consumers of the crops, especially vegetable and salad crops. This concentration represents a major relaxation of earlier standards but is in accord with current standards for bathing water quality; in Europe, for example, this standard is <2000 faecal coliforms per 100 ml (Council of the European Communities, 1976), and it makes little sense to demand a standard for irrigation that is more stringent than that for total body immersion. Recent research (Oragui et al., 1987) has confirmed that at a concentration of <1000 faecal coliforms per 100 ml, which implies a very high removal of faecal coliforms (4–6 $\log_{10}$ units or >99.99%), bacterial pathogens will be either absent or present in only negligible numbers (see Table 4.6). Effluents of this quality are readily produced by a series of 4–6 waste stabilization ponds with an overall retention time of 20 days or more at temperatures above 20 °C (see Section 7.2). Effluents of a higher quality (<100 faecal coliforms per 100 ml, for example) may be required for wastewater used to irrigate public parks and hotel lawns to protect the health of those, especially tourists and young children, who come into contact with recently irrigated grass.

Box 4.2 Rationale for the Engelberg guidelines for the microbiological quality of treated wastewater used for crop irrigation: the Adelboden statement

The very strict microbial standards developed by the California State Health Department and some other groups some 50 years ago of 2 coliforms per 100 ml for effluent irrigation of vegetables and salad crops eaten uncooked were based on a "zero risk" concept. They were partially motivated by the literature on pathogen detection and survival in wastewater and in soil, which suggested that the mere presence of pathogens in the environment is evidence of a serious public health risk. They may also have been influenced by the public opposition to earlier mismanaged raw sewage farms near residential areas, which aroused public health fears on grounds of odour and fly nuisance. These standards were not really feasible with normal wastewater treatment technologies, even in developed countries, but this was of little concern since the health authorities may well have preferred that unrestricted irrigation did not become a widespread practice. It must also be stated that these strict early standards were not based on an analysis of any epidemiological evidence. The California standard rapidly spread throughout the world to most developing countries as the most commonly accepted guideline for wastewater reuse since no other credible source of evidence on this subject existed. However, for some time experts have questioned the validity of this early approach as being unreasonably strict; for example, a WHO Working Group stated "economically and practically a 'no-risk' level cannot be obtained, although it may be technologically possible" (WHO, 1981).

The participants at the Engelberg meeting critically evaluated the massive amount of epidemiological data reviewed and analysed by the World Bank study (Shuval et al., 1986) and the IRCWD/WHO study (Blum & Feachem, 1985) on credible health effects associated with wastewater and excreta use in agriculture. They unanimously concluded that the risks of irrigation with well treated wastewater were minimal and that current bacterial standards were unjustifiably restrictive. However, they did recognize that in many developing countries the main risks were associated with helminthic diseases and that the safe use of wastewater would require a high degree of helminth removal. Thus, the Engelberg guidelines represent a new, stricter approach concerning the need to reduce helminth egg levels in effluents to 1 or less per litre. This represents a requirement to achieve a very effective helminth removal of some 99.9% by appro-

(Box 4.2 continued)

priate treatment processes. Stabilization ponds are particularly effective in achieving this goal but other technologies are also available. While the Engelberg guidelines do not refer specifically to protozoa of public health importance, such as *Amoeba* and *Giardia*, it was understood that the strict helminth standard recommended was selected as an indicator for all of the large easily settleable pathogens including the protozoa. It is thus implied in the Engelberg guidelines that equally high removals of all protozoa will be achieved.

On the other hand, the Engelberg meeting participants concurred that a microbial standard of some 1000 faecal coliforms per 100 ml for unrestricted crop irrigation was both epidemiologically sound and technologically feasible. They also considered that it was much in line with the actual river water quality used for unrestricted irrigation in Europe and the United States with no known ill effects. The group also noted that many countries found levels of 1000 coliforms per 100 ml acceptable for bathing water quality. It was not considered rational to require a stricter standard for unrestricted irrigation than was considered acceptable for general irrigation and bathing by most of the industrialized countries.

Further, the Engelberg meeting participants felt strongly that the irrational application of unjustifiably strict microbial standards for wastewater irrigation had led to an anomalous situation. Standards were often not enforced at all and serious public health problems resulted from totally unregulated illegal irrigation of salad crops with raw wastewater as is in fact widely practised in many developing countries. The Engelberg approach called for realistic revised standards which were stricter for helminth removal but more feasible regarding bacterial levels. It was the combined epidemiological and engineering judgement of the Engelberg group that this new approach would increase public health protection for a greater number of people with goals which were technologically and economically feasible.

For a full analysis of the epidemiological foundations upon which the Engelberg guidelines are based, the reader is referred to the original reports of Shuval et al. (1986) and Blum & Feachem (1985). These guidelines are intended to guide design engineers in the choice of treatment and management technologies that will reliably achieve the standard. Once achieved, there will be no necessity for the continuous monitoring of indicator organism concentrations.

Table 4.6 Geometric mean bacterial and viral numbers[a] and percentage removals in raw wastewater (RW) and the effluents of five waste stabilization ponds in series (P1–P5)[b] in northeast Brazil at a mean mid-depth pond temperature of 26 °C

Organism	RW	P1	P2	P3	P4	P5	Percentage removal
Faecal coliforms	2×10^7	4×10^6	8×10^5	2×10^5	3×10^4	7×10^3	99.97
Faecal streptococci	3×10^6	9×10^5	1×10^5	1×10^4	2×10^3	300	99.99
Clostridium perfringens	5×10^4	2×10^4	6×10^3	2×10^3	1×10^3	300	99.40
Total bifidobacteria	1×10^7	3×10^6	5×10^4	100	0	0	100.00
Sorbitol-positive bifids	2×10^6	5×10^5	2×10^3	40	0	0	100.00
Campylobacters	70	20	0.2	0	0	0	100.00
Salmonellae	20	8	0.1	0.02	0.01	0	100.00
Enteroviruses	1×10^4	6×10^3	1×10^3	400	50	9	99.91
Rotaviruses	800	200	70	30	10	3	99.63

[a] Bacterial numbers per 100 ml, viral numbers per 10 litres.
[b] P1 was an anaerobic pond with a mean hydraulic retention time of 1 day; P2 and P3–P5 were secondary facultative and maturation ponds respectively, each with a retention time of 5 days. Pond depths were 3.4–2.8 m.

Source: Oragui et al. (1987)

4.4.2 Excreta quality for agricultural use

If excreta and excreta-derived products (such as wastewater sludges, composts, septage and latrine contents) are applied to the field before the planting of crops, no quality guidelines are necessary provided that:

- the wastes are placed in trenches and covered with at least 25 cm of soil;
- farm and sanitation workers are adequately protected during this process; and
- root crops are not planted directly over the trenches.

If the waste products are not buried in trenches but are applied as a topsoil dressing (as is common with composts, for instance), or if they are regularly applied to the soil after planting has occurred (as is usually the case with liquid nightsoil), the Engelberg guidelines for wastewater irrigation should be observed (and interpreted as <1 egg per litre or kilogram (wet weight) and <1000 faecal coliforms per 100 ml or 100 g (wet weight) as appropriate). Treatment of nightsoil to achieve the helminth standard for restricted use can be achieved by various technologies, and composting is an effective way to achieve the standard of <1000 faecal coliforms per 100 g for unrestricted use (see Section 7.2.3).

4.4.3 Excreta and wastewater quality for aquacultural use

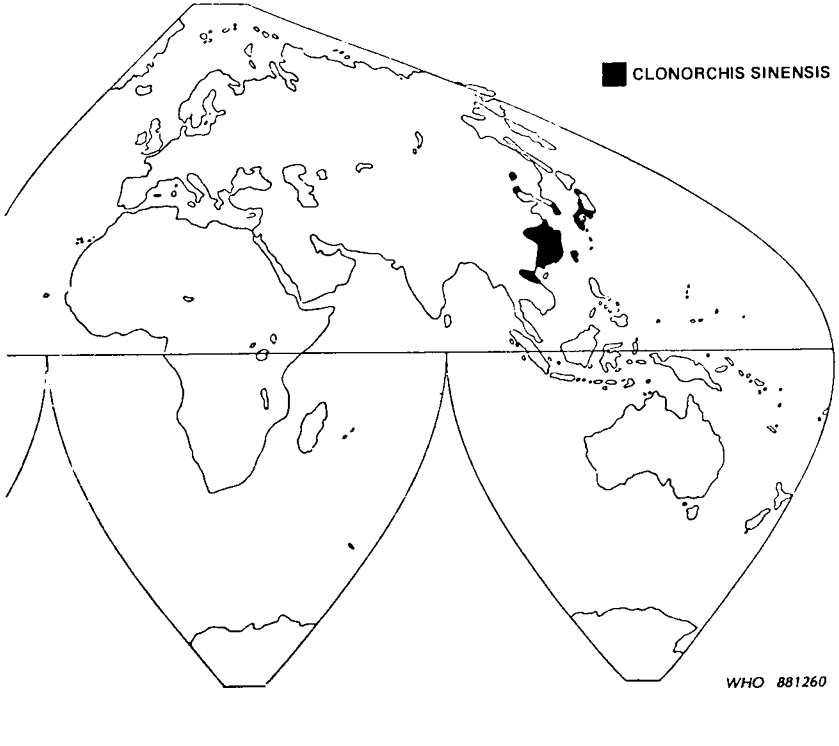
Strauss (1985) has reviewed the literature on the survival of pathogens in and on fish. His principal findings were as follows:

- Invasion of fish muscle by bacterial pathogens is very likely to occur when the fish are raised in ponds that contain concentrations of faecal coliforms and salmonellae of $>10^4$ and $>10^5$ per 100 ml respectively; the potential for muscle invasion increases with duration of exposure of the fish to the contaminated water.
- Even at lower contamination levels, high pathogen concentrations may be present in the digestive tract and the intraperitoneal fluid of the fish.

Further work is needed before a definitive bacteriological quality standard can be established for pisciculture, but a tentative interim guideline would be that fish-pond water should contain <1000 faecal coliforms per 100 ml. The same faecal coliform standard should be applied to ponds in which macrophytes are grown, as these are frequently eaten raw. A further necessary public health measure is to ensure high standards of hygiene during fish handling and especially gutting. This is more feasible in the case of commercial operations than in the case of subsistence aquaculture, for which sustained health education programmes will often be required.

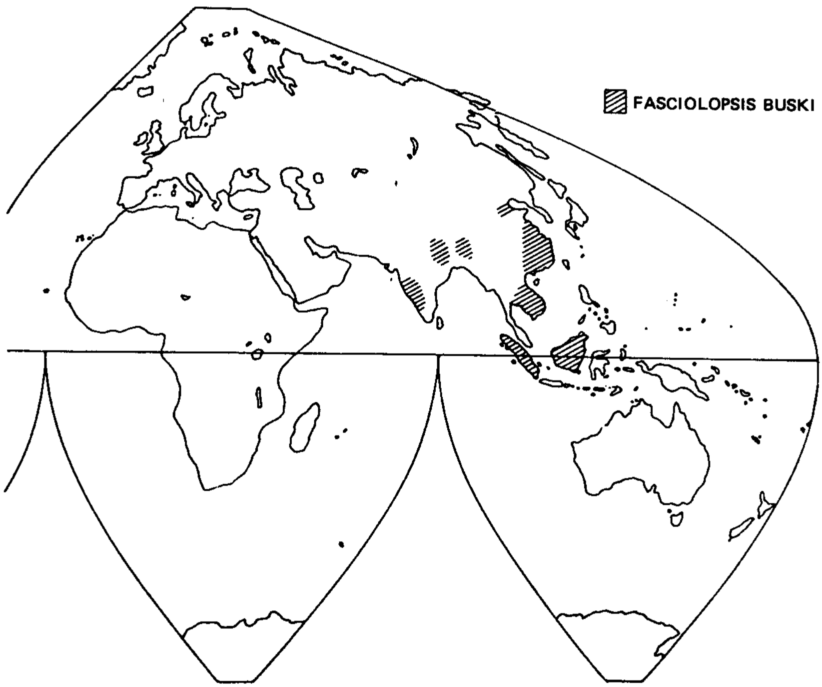
The transmission of clonorchiasis and fasciolopsiasis occurs only in very restricted geographical areas of Asia (see Figures 4.7 and 4.8). Given the cultural preference in these areas for eating raw fish and aquatic vegetables — the second intermediate hosts of these pathogens — transmission can be prevented only by ensuring that no eggs enter the pond or by snail control. The latter option is unlikely to be

Figure 4.7 Known geographical distribution of *Clonorchis sinensis*



From Feachem et al. (1983), reproduced by permission of the World Bank

Figure 4.8 Known geographical distribution *of Fasciolopsis buski*



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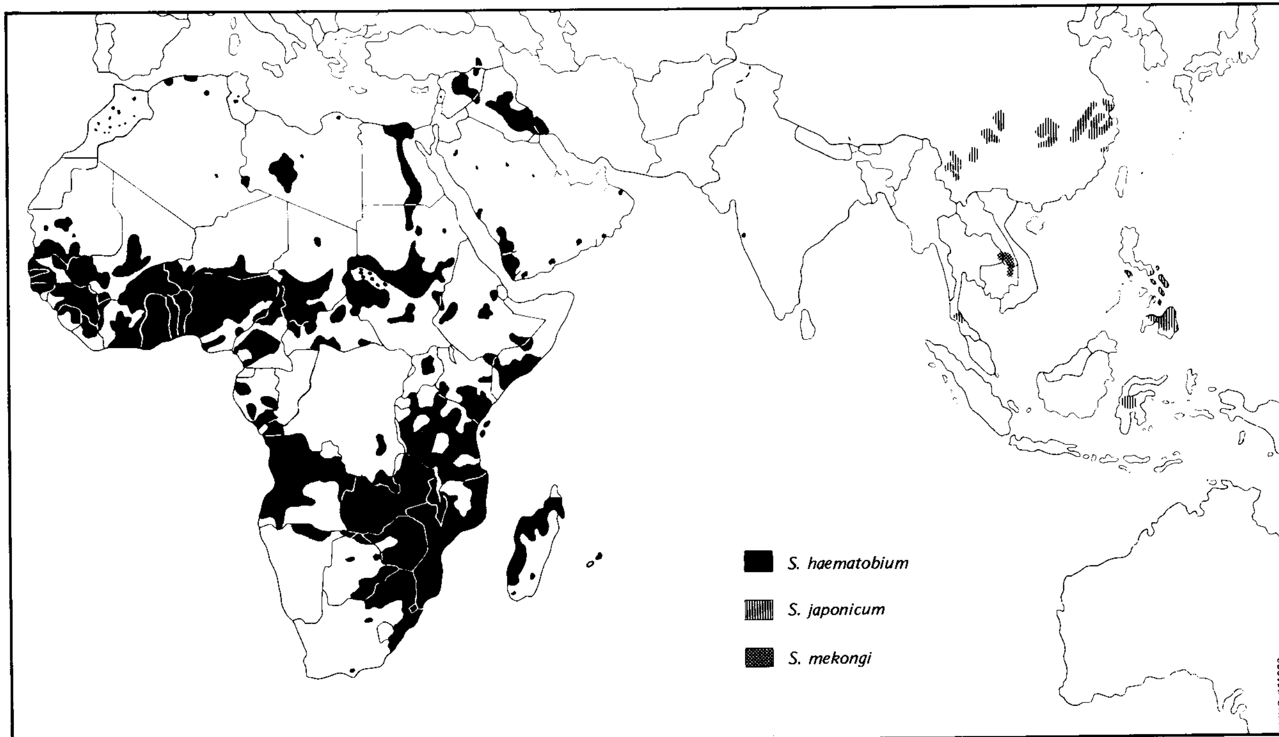
continuously achieved in practice, especially in the small subsistence ponds common in parts of Asia. Thus the only feasible means of control is to remove all viable trematode eggs before excreta and wastewater are applied to ponds—*all* eggs must be rendered non-viable because of the huge asexual multiplication of the pathogen in its first intermediate host. Similar considerations apply to the control of schistosomiasis, which is a potential occupational risk to both fish- and macrophyte-pond workers in a much wider geographical area (see Figures 4.9 and 4.10). The appropriate helminthic quality guideline for all aquacultural use of excreta and wastewater is thus the absence of viable trematode eggs. This is readily achieved in wastewater by pond treatment and in excreta by storage for at least one month (see Section 7.2.4).

Tentative microbiological quality guidelines for aquacultural use, analogous to the Engelberg guidelines for agricultural use, are given in Table 4.7.

Figure 4.9 Known geographical distribution of *Schistosoma haematobium, S. japonicum* and *S. mekongi*



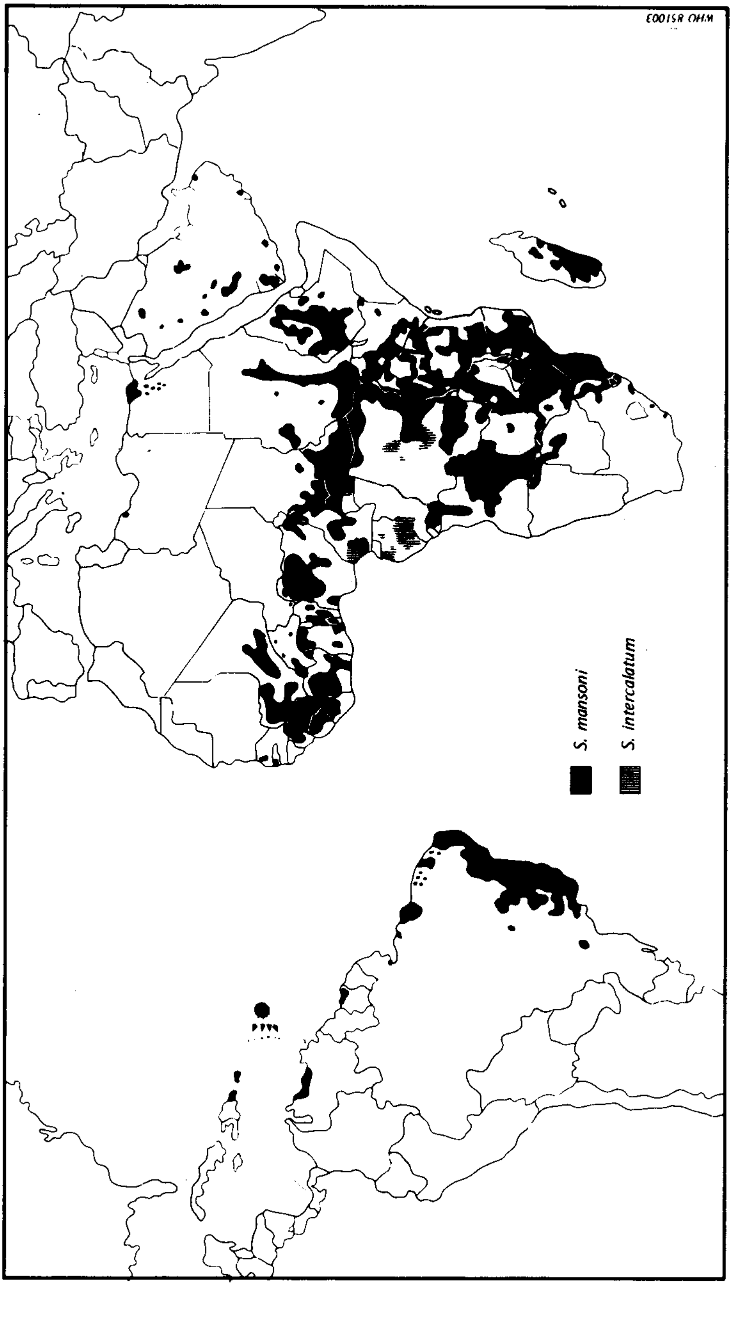


Figure 4.10 Known geographical distribution of *Schistosoma mansoni* and *S. intercalatum*

Table 4.7 Tentative microbiological quality criteria for the aquacultural use of wastewater and excreta

Reuse process	Viable trematode eggs[a] (arithmetic mean number per litre or kg)	Faecal coliforms (geometric mean number per 100 ml or per 100 g)[b]
Fish culture	0	$< 10^4$
Aquatic macrophyte culture	0	$< 10^4$

[a] *Clonorchis, Fasciolopsis* and *Schistosoma*. Consideration need be given to this guideline only in endemic areas (Figures 4.7–4.10).
[b] This guideline assumes that there is a one $\log_{10}$ unit reduction in faecal coliforms occurring in the pond, so that in-pond concentrations are < 1000 per 100 ml. If consideration of pond temperature and retention time indicates that a higher reduction can be achieved, the guideline may be relaxed accordingly.