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Guidelines and integrated measures for public health protection in agricultural reuse systems

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ABSTRACT: Based on a theoretical model predicting a descending order of risks of pathogen transmission by irrigation with raw wastewater, and on extensive epidemiological research done in the past 15 years, a new microbiological quality guideline is proposed in terms of concentration of intestinal nematodes and faecal coliforms. Public health protection of the exposed groups can be attained through integrated measures which includes wastewater treatment, crop selection, appropriate wastewater application and human exposure control. Several recommendations are made in terms of technical and institutional aspects as well as on national policies related to agricultural reuse schemes. Research into a number of subject areas is proposed in order to fill gaps of knowledge in the area of wastewater reuse in agriculture.

Directives et mesures intégrées pour la protection sanitaire dans la réutilisation de déchets à des fins agricoles

RESUME: Une nouvelle Directive sur la qualité microbiologique est proposée à partir d'un modèle théorique qui prévoit un ordre décroissant de risque en ce qui concerne la transmission de pathogènes par l'irrigation des sols avec des eaux usées non traitées, et basée d'autre part sur les recherches épidémiologiques très poussées effectuées ces 15 dernières années. Cette Directive serait déterminée en fonction des concentrations en nématodes intestinales et en coliformes fécales. La protection sanitaire des groupes exposés aux risques est réalisée par une série de mesures intégrées, y compris le traitement des eaux usées, la sélection des cultures, une application appropriée des eaux usées et un contrôle des niveaux d'exposition des êtres humains. Plusieurs recommandations sont données concernant aussi bien les aspects techniques et institutionnels que les politiques nationales en matière de réutilisation agricole. Des études sont proposées sur de nombreux sujets afin de combler les lacunes dans nos connaissances actuelles de la réutilisation des eaux usées à des fins agricoles.

INTRODUCTION

Wastewater recycling through agricultural schemes should be considered as first priority in terms of treatment and disposal of urban wastes. The traditional schemes for treatment and disposal of wastewater should be considered as priority options only if local conditions or cultural problems do not allow for reuse.

The advantages provided by reuse have led the WHO (and other international organizations such as the World Bank, UNDP and FAO) to embark on field studies in order to:

- document the extent of negative health effects from the reuse of wastewater and excreta;
- provide suitable guidelines to governments of developing countries to minimize the health hazards of wastewater reuse;
- encourage countries to utilize treated wastewater for irrigation and soil conditioning and to point out the advantages and the risks involved; and
- encourage appropriate handling of wastewater as an element in the improvement of water resources planning.

RELATIVE IMPORTANCE OF THE BASIC FACTORS OF DISEASE TRANSMISSION

Some groups of pathogens show higher risks of transmitting certain diseases than others. This characteristic is associated with both aspects of disease transmission and host factors. In the case of infections transmitted by wastewater reuse, these constitute the following [1]:

- long persistence in the environment;
- long latent period;
- low infection dose;
- weak host immunity;
- minimal transmission through other routes such as food, water or person-to-person contact;
- poor personal or domestic hygiene.

Current knowledge of these factors as related to groups of important pathogens in wastewater reuse in agriculture and aquaculture as well as major parallel routes of infection for each group is shown in Table 1.

Analysis of the information provided by Table 1 leads to the conclusion that helminths present the highest risks of wastewater-related disease transmission due to long latency periods in the soil required for transmission, long persistence in the environment, a low infective dose, practically no host immunity and the limited possibility of concurrent infection in the home. On the other hand the enteric viruses seem to pose the lowest risk mainly because of the immunity they provide after infections contracted early in life through concurrent routes of transmission at homes in which poor hygiene conditions prevail.

The risks of infections due to protozoa and bacteria are between those of helminths and viruses, giving rise to the following rank in terms of descending order of risk:

(a) high—helminths (intestinal nematodes); *Ascaris* (roundworm); *Trichuris* (whipworm); *Ancylostoma* (hookworm); *Taenia* (tapeworm);
(b) medium—bacteria (cholera, typhoid and shigellosis); protozoa (amebiases, giardiasis);
(c) low—viruses (viral gastroenteritis and infectious hepatitis).

EPIDEMIOLOGICAL EVIDENCE

Epidemiological studies are required to verify the validity of the theoretical model of risks in the descending order associated with wastewater reuse and to determine if excreta or wastewater reuse results in a measurable excess, incidence, prevalence or intensity of disease. Such studies require observation of two populations (exposed and not exposed) divided in subgroups (ages, consumers of wastewater irrigated crops, workers subjected to occupational exposure, etc.) in order to determine the 'excess' or 'attributable risks' involved.

The epidemiological studies available to date on the agricultural use of wastewater have been rigorously reviewed and lead to the following conclusions [1]:

- crop irrigation with untreated wastewater causes significant excess intestinal nematode infection in both consumers (Fig. 1) and farmworkers (Fig. 2); the latter,

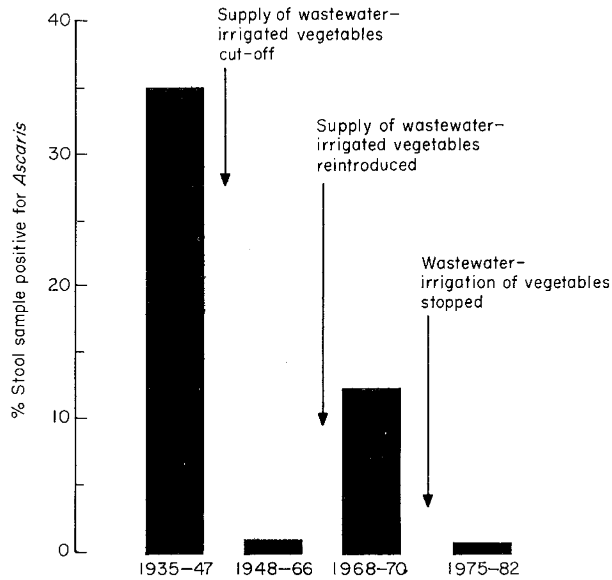

Fig. 1. Relationship between *Ascaris*-positive stool samples in the population of western Jerusalem and the availability of vegetables and salad crops irrigated with raw wastewater in Jerusalem, 1935–82 [1].

Table 1. Basic factors of disease transmission for groups of pathogens associated with wastewater reuse [1]

Pathogen	Persistence	Latency	Infective dose	Immunity	Major parallel routes of infection	Soil stage
Helminths	long	long	low	none or little	soil, crops	yes
Protozoa	short	zero	low to medium	none or little	person-to-person, food, water	no
Bacteria	short to medium	zero	medium to high	short to medium	person-to-person, food, water	no
Viruses	medium	zero	low	long	person-to-person, food water	no

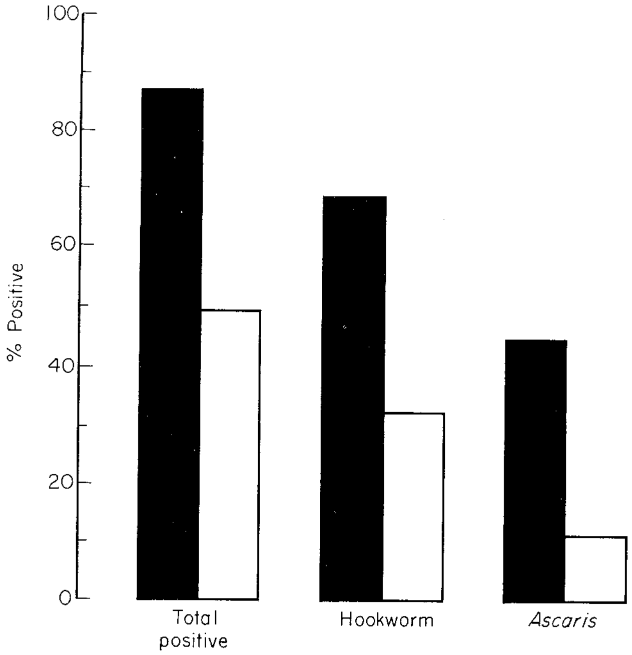

Fig. 2. Prevalence of hookworm and *Ascaris* infections in sewage-farm workers (■, n = 466) and control groups (□, n = 432) in various regions of India [2].

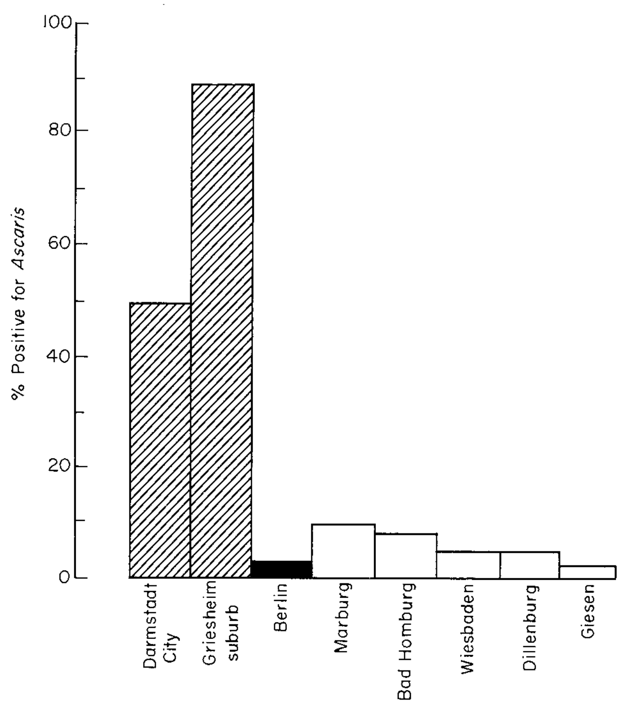

Fig. 3. Wastewater irrigation of vegetables and ascariasis prevalence in Darmstadt, Berlin and other German cities in 1949. Raw wastewater was used for irrigation in Darmstadt (▨) and conventionally treated wastewater (primary sedimentation, biofiltration and secondary sedimentation) in Berlin (■) [1].

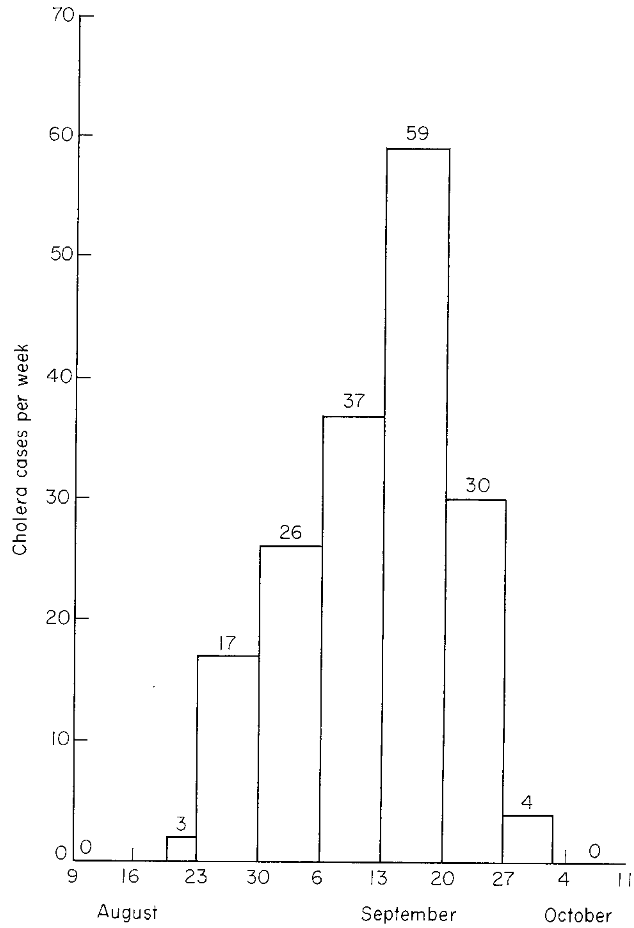

Fig. 4. Weekly distribution of cholera cases in Jerusalem, August–September 1970 (n = 176). Irrigation of vegetables and salad crops with raw wastewater was stopped by the authorities during the week beginning 13 September [1].

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

- crop irrigation with treated wastewater does not lead to excess intestinal nematode infection amongst field workers or consumers (Fig. 3);
- cholera, and probably also typhoid, can be effectively transmitted by the irrigation of vegetables with untreated wastewater (Fig. 4);
- cattle grazing on pastures irrigated with raw wastewater may become infected with *Cysticerus bovis* (the larval stage of the beef tapeworm, *Taenia saginata*) but there is little evidence of actual risks of human infection;
- there is limited evidence that the health of people living near fields irrigated with raw wastewater may be negatively affected either by direct contact with the soil, or indirectly through contact with farm labourers; in com-

munities with high standards of personal hygiene such negative impacts are usually restricted to an excess incidence of benign gastroenteritis, often of viral aetiology, although there may also be an excess of bacterial infections; and

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

These findings make clear that when untreated wastewater is used for crop irrigation, helminths and bacteria present higher actual risks and that viruses show little or no actual risks. The actual risks due to protozoa are not yet well established as no sufficient epidemiological data are available but no studies have shown that wastewater reuse causes additional risk. The theoretical model assuming the descending order of risks from helminths to viruses is in accordance with and supports these conclusions.

EFFLUENT QUALITY MICROBIAL GUIDELINES

The very strict microbial standards developed over 50 years were based on *potential risks* associated with pathogen

Table 2. Health guidelines and suggested wastewater treatment systems according to WHO (1973) [4]

	Irrigation			Recreation			Municipal reuse	
	Crops not for direct human consumption	Crops eaten cooked; fish culture	Crops eaten raw	No contact	Contact	Industrial reuse	Non-potable	Potable
Health criteria (see below for explanation of symbols)	A+F	B+F or D+F	D+F	B	D+G	C or D	C	E
Primary treatment	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
Secondary treatment		●●●	●●●	●●●	●●●	●●●	●●●	●●●
Sand filtration or equivalent polishing methods		●	●		●●●	●	●●●	●●
Nitrification						●		●●●
Denitrification								●●
Chemical clarification						●		●●
Carbon adsorption								●●
Ion exchange or other means of removing ions						●		●●
Disinfection		●	●●●	●	●●●	●	●●●	●●●*

Health criteria:
A Freedom from gross solids; significant removal of parasite eggs.
B As A, plus significant removal of bacteria.
C As A, plus more effective removal of bacteria, plus some removal of viruses.
D Not more than 100 coliform organisms per 100 ml in 80% of samples.
E No faecal coliform organisms in 100 ml, plus no virus particles in 1000 ml, plus no toxic effects on man, and other drinking-water criteria.
F No chemicals that lead to undesirable residues in crops or fish.
G No chemicals that lead to irritation of mucous membranes and skin.
In order to meet the given health criteria, processes marked ●●● will be essential. In addition, one or more processes marked ●● will also be essential, and further processes marked ● may sometimes be required.
*Free chlorine after 1 hour.

survival in wastewater soil and crops rather than in the *actual risks* which are supported by epidemiological evidence.

For example, the California State Health Department standards [3] permit only 23 or 2.3 total coliforms per 100 ml depending on the crop being irrigated and on the irrigation method, and the 1973 World Health Organization Guidelines allow only 100 total coliforms per 100 ml for unrestricted irrigation [4] as shown in Table 2.

Most of the standards and guidelines were expressed in terms of total and/or faecal coliform bacteria with the maximum permissible coliform concentration set at very low values. The reason for this is probably associated with the choice of technology prevailing 10–20 years ago; secondary treatment followed by effluent chlorination allowing for BOD and coliform removal. Since chlorination could easily achieve very low residual coliform concentrations, the maximum permissible coliform concentrations were set accordingly low.

After the WHO Meeting of Experts on the Reuse of Effluents [4] major efforts were undertaken by WHO, the World Bank, UNDP, UNEP, IDRC (Canada), IRCWD (Switzerland), FAO, USAID and several universities and institutions throughout the world to provide epidemiological evidence to support more rational wastewater irrigation guidelines. The results and recommendations of these studies were reviewed by public health experts, environmental scientists and epidemiologists at meetings in Engelberg [5] and Adelboden, [6] Switzerland and finally at the Scientific Group Meeting on Health Effects of Wastewater Use held in Geneva on 18–23 November 1987 [7].

The consensus views were that the actual risk of irrigation with treated wastewater is much lower than previously estimated and that the early microbial standards and guidelines for effluent to be used for unrestricted irrigation of vegetables and salad crops, normally consumed uncooked, were unjustifiably restrictive particularly with respect to bacterial pathogens. After consideration of the preparatory work made at Engelberg and Adelboden and the epidemiological evidence now available, the Scientific Group Meeting recommended the guidelines shown in Table 3.

Table 3. Recommended microbiological quality guidelines for wastewater use in agriculture* [7]

Category	Reuse conditions	Exposed group	Intestinal nematodes† (arithmetic mean no. of eggs per litre)‡	Faecal coliforms (geometric mean no. per 100 ml)‡	Wastewater treatment expected to achieve microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks§	workers consumers public	$\leqslant 1$	$\leqslant 1000$	a series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees¶	workers	$\leqslant 1$	not applicable	retention in stabilization ponds for 8–10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	none	not applicable	not applicable	pre-treatment as required by the irrigation technology, but no less than primary sedimentation

*In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and these Guidelines modified accordingly.
†*Ascaris, Trichuris* and hookworms.
‡During the irrigation period.
§A more stringent guideline ($\leqslant$ 200 faecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may have direct contact.
¶In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

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A bacterial guideline of a geometric mean of 1000 faecal coliforms/100 ml for unrestricted irrigation of all crops is recommended based mainly on the following considerations:

- natural die-away of pathogens in the irrigation fields constitutes a valuable additional safety factor in reducing potential health risks. Pathogen inactivation by ultraviolet radiation, desiccation and by natural biological predators when effluent is applied to crops and soils can often provide an additional 90–99% reduction of pathogens within a few days after application;
- field and laboratory studies indicate that wastewater effluent with 1000 faecal coliforms/100 ml contains few, if any, detectable pathogens;
- typical levels of faecal coliform concentrations in rivers throughout the world are significantly high. It can be seen from Table 4 that in about 45% of the rivers included in the survey [8], faecal coliform concentrations were 1000/100 ml or greater, and almost 15% had concentrations of 10 000/100 ml or more. Water from such rivers outside the United States is widely used for irrigation with no legislative restriction on its use. In 1973, the US Environmental Protection Agency, together with the US Academy of Sciencies, recommended that the acceptable guidelines for irrigation with natural surface water, including river water, be set at 1000 total coliforms per 100 ml [9];
- the microbial guidelines and standards for bathing water quality developed by the UNEP/WHO MED POL programme [10] established 1000 faecal coliforms per 100 ml and the Guidelines recommended by the European Economic Community [11], established less than 10 000 total coliforms per 100 ml and less than 2000 faecal coliforms per 100 ml.

It was the unanimous opinion of the Scientific Group that it was not reasonable or rational to support the historic faecal coliform wastewater irrigation guidelines which were at a level approaching drinking-water quality when actual natural river waters and sea water used for swimming are considered acceptable by health authorities with faecal coliform concentrations of 1000/100 ml or more.

On the other hand the experts who gathered at the Scientific Group Meeting recognized that the main actual health risks in many developing countries were associated with helminthic diseases and that the safe use of wastewater in agriculture would require a high degree of helminth removal. Thus, the new guidelines represent an accurate approach concerning the needs to reduce helminth eggs in effluents to a level of 1 or less per litre.

TECHNICAL ASPECTS—MEASURES FOR HEALTH PROTECTION

Health protection in wastewater reuse schemes can be provided by the integrated application of four major measures: wastewater treatment, crop restriction, wastewater application control, and human exposure control and hygiene.

Wastewater treatment

Methods of wastewater treatment were first developed mainly in response to the concern for the adverse conditions caused by the discharge of wastewater into the environment. The objectives of early treatment were to (a) remove suspended and floatable material, (b) treat biodegradable organics, and (c) eliminate pathogenic organisms. In August 1973 the US Environmental Protection Agency published its definition of secondary treatment including three major effluent parameters: 5-day BOD, suspended solids and pH [12]. A coliform standard included in the original version was deleted in July 1976 [13], probably due to the concern associated with chlorine and effects of chlorine compounds on the aquatic environment and trihalomethane formation.

Table 4. Faecal coliforms in rivers surveyed by GEMS [8]

Number of faecal coliforms per 100 ml	No. of rivers in each region*			
	North America	Central and South America	Europe	Asia and Pacific
< 10	8	0	1	1
10–100	4	1	3	2
100–1000	8	10	9	14
1000–10 000	3	9	11	10
10 000–100 000	0	2	7	2
> 100 000	0	2	0	3
Total number of rivers	23	24	31	32

*No data from Africa reported.

Table 5. Expected removal of excreted bacteria and helminths in various wastewater systems [6,14]

Treatment process	Removal ($\log_{10}$ units) of			
	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0–1	0–2	0–1	0–1
Chemically assisted*	1–2	1–3††	0–1	0–1
Activated sludge†	0–2	0–2	0–1	0–1
Biofiltration†	0–2	0–2	0–1	0–1
Aerated lagoon‡	1–2	1–3††	1–2	0–1
Oxidation ditch†	1–2	0–2	1–2	0–1
Disinfection§	2–6††	0–1	0–4	0–3
Waste stabilization ponds¶	1–6††	1–3††	1–4	1–4
Effluent storage reservoirs**	1–6††	1–3††	1–4	1–4

*Further research is needed to confirm performance.
†Including secondary sedimentation.
‡Including settling pond.
§Chlorination or ozonation.
¶Performance depends on number of ponds in series and other environmental factors.
**Performance depends on retention time, which varies with demand.
††With good design and proper operation the recommended guidelines are achievable.

The same treatment criteria mainly for BOD removal are still being followed in several parts of the world when planning treatment schemes for wastewater reuse. Since new guidelines are now being provided, criteria for wastewater treatment should change accordingly in order to attain appropriate effluent quality. Table 5 summarizes the available information on removal of the excreted bacteria pathogens and helminths and indicates where the proposed guidelines for category A irrigation (Table 3) can be met [6,14].

The following can be considered for treatment systems in terms of their appropriateness for wastewater treatment utilized in irrigation systems.

Conventional primary and secondary treatments. Raw wastewaters contain 10^7–10^9 faecal coliforms per 100 ml and it is clear from Tables 3 and 5 that conventional systems (plain sedimentation, biofiltration, aerated lagoons, activated sludge and oxidation ditches) cannot produce an effluent which complies with the new guidelines for bacterial quality (< 1000 faecal coliforms per 100 ml).

It must also be considered that conventional wastewater systems are not generally effective for helminth removal. There is a need for research and development work to improve the helminth egg removal efficacy of conventional systems so as to meet the recommended microbiological guidelines.

Waste stabilization ponds. This is usually the preferred method of wastewater treatment in warm climates whenever land is available at reasonable costs [15,16]. Ponds in series of anaerobic, facultative and maturation units with an overall average of hydraulic detention time of 10–50 days (depending on temperature) can be designed to produce effluents which meet the proposed guidelines for both bacterial and helminthic quality. The presence of free-living nematode larval stages in stabilization-pond effluents, sometimes in large numbers, is of no public health significance because they are not pathogenic to human beings.

Tables 6 [17] and 7 [18,19] indicate the high confidence with which pond series can meet the proposed guidelines in terms of faecal coliforms and nematode eggs. The series of ponds referred to in Table 7 also shows the excellent removals of BOD and suspended solids provided by the treatment system.

Table 6. Reported effluent quality for several series of waste stabilization ponds, each with a retention time of 25 days [17]

Pond system	No. of ponds in series	Effluent quality (FC/100 ml)*
Melbourne, Australia	8–11	100
Extrabes, Brazil	5	30
Cogolin, France	3	100
Amman, Jordan	9	30
Lima, Peru	5	100
Tunis, Tunisia	4	200

*FC = Faecal coliforms

Table 7. Performance of a series of five waste stabilization ponds in north-east Brazil (mean pond temperature: 26°C) [18,19]

Sample	Retention time (days)	BOD_5 (mg/l)	Suspended solids (mg/l)	Faecal coliforms	Intestinal nematode eggs (/litre)
Raw wastewater	—	240	305	4.6×10^7	80^4
Effluent from					
Anaerobic pond	6.8	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
Maturation pond 1	5.5	25	61	2.4×10^4	0
Maturation pond 2	5.5	19	43	450	0
Maturation pond 3	5.8	17	45	30	0

If land is not a severe constraint, stabilization ponds should be the preferred process to produce wastewater effluents suitable for crop irrigation.

Disinfection. Disinfection of wastewater, usually done through application of chlorine, has never been completely successful in practice due to the difficulties in maintaining a uniform and predictable level of disinfecting efficiency. Effluents from well-operated conventional treatment systems treated with 10–30 mg/l of chlorine (depending on the concentration of organics) and a contact time of 30–60 min will provide a good reduction of excreted bacteria but will have no capacity for removing helminths and protozoa [14].

Due to the complexity of operation and maintenance, high costs and lack of consistency on disinfecting efficiency, the process should not be recommended for reuse in agriculture in developing countries. If more reliable treatment systems such as stabilization ponds can provide effluents which meet the proposed guidelines there is no need for disinfection.

Storage reservoirs. Since demand for irrigation is usually concentrated in the dry season or in some particular periods of the year, wastewater can be stored in large reservoirs, thus providing further treatment, especially concerning bacteria and helminth reduction. Such storage reservoirs are used in Mexico and Israel [1]. There are at present insufficient field data on their performance to formulate a rational design process, but it is clear that pathogen removal will be strengthened by dividing them into compartments connected in series. The greater the number of compartments and the longer the minimum period of retention time, the more efficiently the pathogens will be removed. An appropriate design recommendation might be to provide a minimum hydraulic detention time of 10 days during the irrigation season, and to assume only two $\log_{10}$ unit reduction of both faecal coliform and helminth eggs. Thus, the effluent being discharged into the reservoir should contain no more than 100 helminths' eggs per litre, and if it is to be used for unrestricted irrigation, not more than 100 000 faecal coliforms per 100 ml during irrigation.

Sludge treatment. The sludges originated from the settling units of some wastewater treatment systems show high concentration of pathogens existing in the wastewater including helminth eggs which may remain viable for up to a year. No treatment is required, however, if it is applied to land by subsurface injection or placed in trenches prior to the start of the growing season [6]. For other methods of land application the following treatment methods may be considered in order to meet the recommended guidelines:

- storage for 6–12 months at ambient temperatures in a hot climate situation;
- anaerobic digestion. Anaerobic digestion plants operating at temperatures lower than mesophilic temperatures show parasite egg removals from 90–95% but only 30–40% removal of ascaris [20]. Batch thermophilic digestion at 50°C for 13 days will ensure the inactivation of all pathogens. Batch digestion is required to avoid pathogen short circuiting [6];
- forced aeration co-composting. Co-composting of sludges with domestic solid waste or some other organic bulking agent as wood chips for 30 days at 55–60°C and further maturation for 2–4 months at ambient temperature will produce a stable pathogen-free compost [21].

Tertiary treatment. Tertiary treatment systems were originally developed to improve the quality of secondary treatment systems (activated sludge or trickling filters). Mechanisms designed to improve physico-chemical quality (rapid sand filtration, nitrification, denitrification, carbon adsorption) have little or no effect on excreted bacterial removal, but some (such as filtration) may be effective in removing helminths. Further research is needed to provide reliable design data. These systems, however, are usually complicated and expensive, and their use in developing countries to produce suitable effluents for crop irrigation is not recommended [6].

Crop selection

Crops can be grouped in two broad categories according to the exposed groups and the degree to which health protection measures are required.

Category A. Protection required for consumers, agricultural workers, and the general public. This category includes crops likely to be eaten uncooked, spray-irrigated fruits, sports fields, public parks and lawns.

Category B. Protection required for agricultural workers only (crop restriction). This includes irrigation of cereal crops, industrial crops (e.g. cotton, sisal, etc.), food crops for canning, fodder crops, pastures and trees. Some vegetable crops may be considered under this category if they are not eaten raw (such as potatoes) or if they grow well above the ground (such as chilies, tomatoes and green beans). In this case, it is necessary to ensure that contamination of the crop is not caused by sprinkler irrigation or by falling on the ground, and that contamination of kitchens by such crops before cooking does not give rise to health risks.

To keep crops restricted to Category B the following conditions should be feasible:

- where a law-abiding society or strong law enforcement exists;
- where a public body controls allocation of the wastes;
- where an irrigation project has strong central management;
- where there is adequate demand for the crops allowed under crop restriction, and where they fetch a reasonable price;
- where there is little market pressure in favour of excluded crops (Category A).

Wastewater application

Application of water irrigation to land can be done in the following ways:

- by flooding or border irrigation, wetting almost all the land surface;
- by furrows, wetting only part of the ground surface;
- by sprinklers, so that the soil and crops are wetted in much the same way as by rainfall;
- by subsurface irrigation, by which the surface is wetted little, if any, but the subsoil is saturated; and
- by localized (trickle, drip or bubbler) irrigation; water is applied to each individual plant at an adjustable rate.

Basic information and special measures on each method are included in Table 8 [6].

Human exposure control

The group of people that are most susceptible to potential risk from the reuse of wastewater in agriculture are the following:

- agricultural fieldworkers and their families;
- crop handlers;
- consumers of crops, meat and milk originating from the wastewater irrigated fields;
- those living near the affected fields.

Irrigation method	Factors affecting choice	Special measures for wastewater
Border (flooding) irrigation	lowest cost, exact levelling not required	thorough protection for field workers, crop handlers and consumers
Furrow irrigation	low cost, levelling may be needed	protection for field workers, possibly for crop handlers and consumers
Sprinkler irrigation	medium water use efficiency, levelling not required	some category B crops, especially tree fruit, should not be grown. Minimum distance 50–100 m from houses and roads; anaerobic wastes should not be used, due to odour nuisance
Subsurface and localized irrigation	high cost, high water use efficiency, higher yields	filtration to prevent emitters clogging

Table 8. Factors affecting the choice of each irrigation method, and the special measures required when wastewater is used, particularly when it does not meet the proposed guidelines [6]

The methods for eliminating or minimizing exposure depend on the target groups and are outlined below:

Agricultural fieldworkers and their families and crop handlers. Higher potential risks mainly with respect to parasitic infections. Protection can be done through:
- use of appropriate footwear to reduce hookworm infection;
- use of gloves (mainly for crop handlers);
- health education;
- personal hygiene;
- immunization against typhoid and hepatitis A;
- regular chemotherapy mainly for intense nematode infections in children and control of anaemia;
- provision of adequate medical facilities to treat diarrhoeal diseases.

Consumers. Protection can be done through:
- cooking of vegetables and meat and by boiling milk;
- high standards of personal and food hygiene;
- health education campaigns;
- meat inspection (where there is risk of tapeworm infections);
- ceasing the application of wastes at least 2 weeks before cattle are allowed to graze (where there are risks of bovine cysticercosis);
- ceasing the irrigation of fruit trees two weeks before the fruits are picked;
- information on the location of the wastewater irrigation fields and posting warning notices along the edges of the fields.

People living near the wastewater irrigated fields. There is no epidemiological evidence that the aerosols from sprinkler irrigation scheme cause significant risks on pathogen contamination. However, in order to allow for a reasonable margin of safety and to minimize odour a minimum distance of 100 m should be kept between houses and roads and sprinkler systems.

INTEGRATION OF THE VARIOUS MEASURES FOR HEALTH PROTECTION

To the planners and decision makers concerned with wastewater reuse, wastewater treatment appears as a more straightforward and 'visible' measure for health protection, seconded only by crop restriction. Both measures, however, are relatively difficult to implement fully: the first limited by costs and problems of operation and maintenance, and the second by lack of appropriate markets for specific products or by legal and/or institutional constraints.

It should be considered that the application of isolated measures, while not economical, may have only partial effects in terms of health protection. Crop restriction, for instance, if applied may protect the consumers of crops but does not provide protection to farmworkers and their families.

In order to analyse the various measures under an integrated fashion aiming at the optimization of the health protection scheme, a generalized model [6,7,22] has been proposed. It was conceived to help in decision making, exposing the range of options for protecting agricultural workers and the crop-consuming public allowing for flexibility of response to different situations. Each situation can be considered separately and the most appropriate option chosen taking into account economic, cultural and technical factors. The graphical conception of the model is shown in Fig. 5.

It was assumed that pathogens flow to the centre of the circle going through the five concentric bands representing wastewater or excreta, field or pond, crop, workers and consumers. The thick black circle represents a barrier beyond which pathogens should not pass if health is to be protected. The level of contamination of wastewater, field or crop or the level of risk to consumer or worker is shown by the intensity of shading. White areas in the three outer bands indicate zero or no significant level of contamination and in the inner bands a presumed absence of risk to human health, and therefore that the strategy leads to 'safe' use of wastewater.

If no protective measures are taken both workers and consumers will be at the highest risk of contamination. Assuming crop restriction is applied (Regime A, Fig. 5) consumers will be safe but workers will still be at high risk. Regime B assumes that application of wastewater is made through subsurface or localized irrigation avoiding crop contamination and consequently maintaining both workers and consumers virtually free of contamination.

If human exposure control is the only protective measure assumed both consumers and workers will still be submitted to the same level of risk since such measures are rarely fully effective in practice. Regime D assumes partial treatment of wastewater through ponding (D-I) or conventional systems (D-II). Stabilization ponds with an average detention time of 8–10 days provide good helminth egg removal, and hence protection to the workers. However, a reduction of bacteria is not enough to meet the proposed guidelines so the risk to consumers will remain high. With conventional systems it does not provide a sufficient helminth egg removal and a small level of risk still remains for both workers and consumers. The following three regimes, E, F, and G, are examples of the combination of protective measures. Regime E includes partial treatment and crop restriction. In this case full protection is provided to consumers but only treatment by ponding systems will provide full protection to workers. In Regime F human exposure control is added to partial treatment. The combination of the two measures

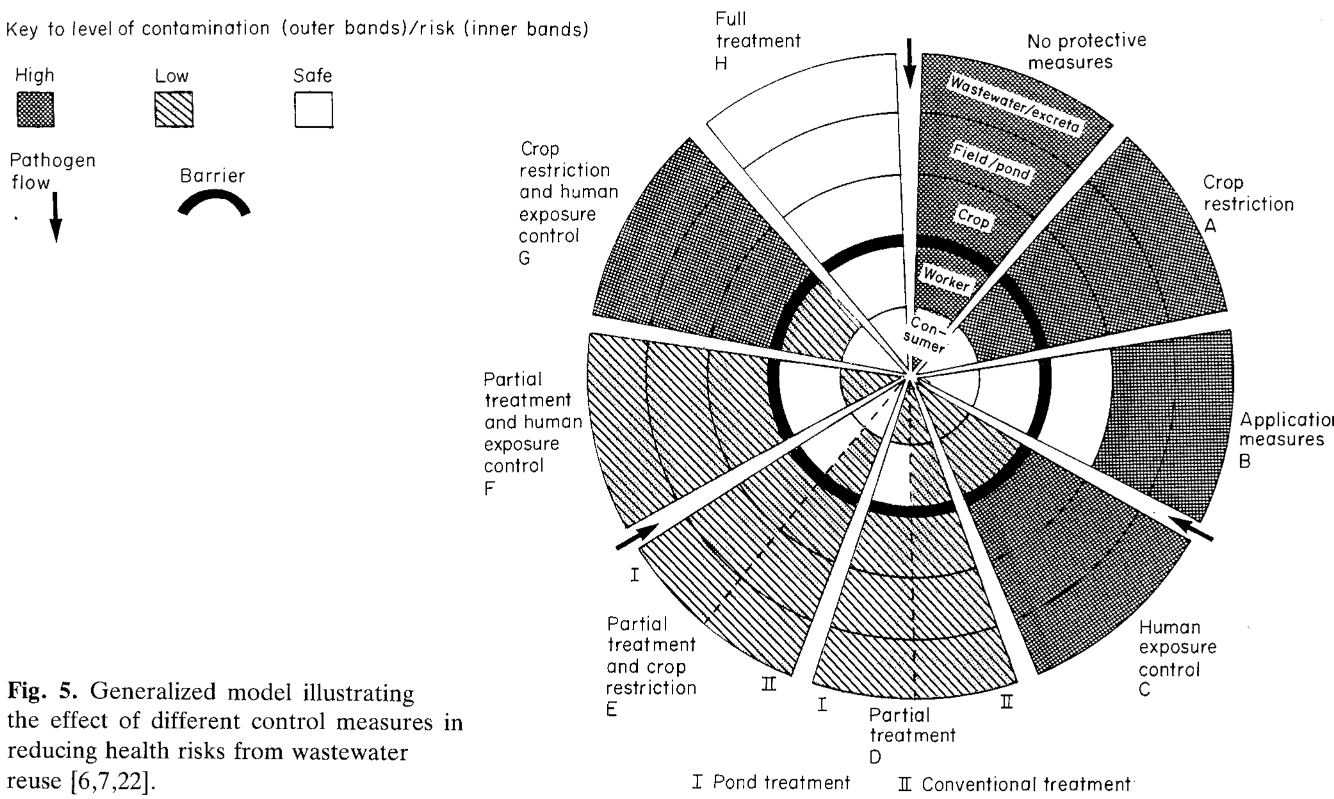

Fig. 5. Generalized model illustrating the effect of different control measures in reducing health risks from wastewater reuse [6,7,22].

may lead to complete protection of the works but some low level of risk still remains to the consumers.

Associating crop restriction and human exposure control (Regime G) will provide full protection to consumers but some risks to the workers will still remain.

Finally, Regime H includes full treatment of wastewater which will provide complete protection to both workers and consumers. The feasibility and efficacy of any combination of measures will depend on several local factors that must be carefully considered before a final choice is made. These include:

- availability of resources (institution, staff, funds);
- existing social and agricultural practices; and
- existing patterns of excreta-related diseases.

CONCLUSION AND RECOMMENDATIONS

The Scientific Group Meeting on Health Aspects of Wastewater Reuse held in WHO, Geneva, on 18–23 November 1987 made a deep and careful review of the available literature, research findings and case studies collected during the last decade by leading organizations and universities of the world. These works and studies were provided through the efforts made by the United Nations Environmental Programme, World Health Organization, World Bank, Food and Agriculture Organization, The International Reference Centre for Wastewater Disposal, the London School of Hygiene and Tropical Medicine, The Hebrew University of Jerusalem, the University of Leeds, the University of Newcastle-upon-Tyne and others. The available information, mainly with respect to extensive epidemiological data and case studies from several developing countries, was reviewed in two previous meetings (Engelberg, Switzerland, in July 1985, and Adelboden, Switzerland, in June 1987) attended by experts, environmental scientists and epidemiologists involved with health aspects of wastewater and excreta use in agriculture and aquaculture.

The Scientific Group meeting was held in order to fulfil the following objectives:

- to review the use of wastewater in agriculture and aquaculture and its health effects;
- to recommend guidelines and alternative measures for the control of infectious disease transmission based on epidemiological findings and technological advances in wastewater treatment process in the last 10–15 years;
- to recommend quality control of treated wastewater for use in agriculture and aquaculture and to identify gaps for further research and development.

A short résumé of the conclusions and recommendations of the Scientific Group are as follows:

- municipal wastewater is a valuable resource which should be utilized with adequate health safeguards since it promotes reduction in the environmental pollution and increases agricultural production;
- reuse of wastewater should be considered the preferred method of disposal and treated as an integral part of water resources planning;
- in order to provide health safeguards to the exposed groups wastewater reuse should be done through an integrated set of measures which includes wastewater treatment, crop restriction, appropriate wastewater application and human exposure control;
- governments are urged to adopt standards based on the proposed microbiological guidelines appropriate to various types of irrigation conditions. The proposed microbiological guidelines should be correctly adapted to local epidemiological, socio-cultural and environmental factors as stated in Table 3. Planners should consider that the excess risk associated with wastewater reuse can be very large in developed countries where high standards of hygiene prevail and provide adequate measures for health protection;
- since not enough epidemiological evidence is available, tentative guidelines have been suggested for wastewater reuse in aquaculture;
- stabilization ponds should be preferred to conventional treatment systems for reuse schemes due to their simplicty and ability to remove pathogens with consistency;
- health protection measures must be monitored and evaluated to ensure their effectiveness in order to contribute towards the validation of the recommended guidelines;
- governments wishing to promote wastewater use in agriculture or aquaculture or to reduce health risks of current practice will find it advantageous to require the involvement and cooperation of several ministries and concerned government agencies in order to promote adequate institutional arrangements;
- WHO should disseminate the findings of the Scientific Group Meeting and should assist Member States in planning and implementing wastewater reuse schemes and in developing appropriate legislation, institutions and training programmes to enable them to achieve health protection.

By assuming that the use of wastewater in agriculture and aquaculture is increasing in importance around the world and because it is a rapidly developing field, the Scientific Group proposed that research into a number of subject areas needs to be continued and intensified. The basic topics listed are:

- wastewater quality assessment;
- wastewater treatment technology;
- wastewater application technology;
- human exposure control;
- socio-cultural research and integration measures;
- epidemiological research;
- aquaculture research.

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