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HEALTH SAFETY IN WASTEWATER REUSE IN IRRIGATED AGRICULTURE

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ABSTRACT – Literature is abundant on wastewater reuse in agriculture but are quite limited the studies concerning safety issues to minimise the health risk from using wastewater in irrigation. Based upon a Unesco book produced by the author where these subjects are treated, main issues to favour health safety of consumers, farmers and other agents are discussed herein. Thus, a review is presented focusing on health concerns, the need to better consider about the need for more stringent water treatments, the suitability of irrigation methods, the need to apply crop restrictions when wastewater contamination hazards are not avoidable, the need to consider the promotion of safe crop production areas, and the consequent requirements for monitoring and control, which may lead to the certification of products, producing areas and farmers. The presentation mainly aims at provoking a discussion on such issues and using a few positive case studies in the Mediterranean area.

Keywords: health risks, pathogens in wastewater, water treatment and disinfection, irrigation methods and practices, crop restrictions, safe production areas, monitoring and control

RESUMÉ – *La literature relative à la reutilization des eaux usées en agriculture est assez abondante mais, au contraire sont peu les etudes concernant les measures et pratiques de securité qui minimisent les risques de santé lies à l'usage des eaux usées en irrigation. Ayant comme base un livre produit par l'auteur pour l'Unesco oú ces sujets sont abordés, cet'article discute des aspects essentials relatifs à la protection de la santé publique liée à l'utilisation des eaux usées tant pour les consommateurs que pour les irrigants et d'autres agents. On présente une revision sur les aspects epidémiologiques et les charactéristiques sanitaires des eaux usées, des questions tenant aux traitements des eaux et leur choix, sur l'adéquation des methods d' irrigation, sur le besoin d'appliquer des restrictions aux cultures lorsque la contamination par les eaux usées est à prevoir, aussi bien que la promotion de zones de production oú la securité sanitaire est assurée et oú le monitorage et contrôle sont appliqués regulièrement de façon à permetter la certification des produits, des fermes et de la zone de production. Cette presentation a comme objectif premier celui de produire une bonne discussion sur les questions traitées et sur des etudes de cas en Mediterranée.*

Mots-clés: *risques sanitaires, pathogènes dans les eaux usées, traitement et disinfection des eaux, méthodes et pratiques d'irrigation, restrictions aux cultures, monitorage et contrôle, certification*

INTRODUCTION

The wastewater use in irrigated agriculture is essential to cope with water scarcity (e.g. Okun, 2000; Hamdy, 2001; Karajeh and Hamdy, 2001; Pereira *et al*., 2002; Choukr-Allah and Hamdy, 2004). Several advantages may be related to such use: adding to limited available water supplies; decreasing/preventing pollution of rivers and other water bodies; conserving high quality water for more stringent water uses; conserving nutrients in wastewaters, so decreasing the amount of fertilizers use and increasing crop yields; and constitutes an easy and low-cost disposal for wastewater. However, the use of wastewater in irrigation involves risks and negative impacts of great importance such as: heath risks for irrigators due to contact with contaminated water, health risks for the consumers due to contaminants incorporated in products, deterioration of surface and ground-waters due to non controlled water applications, deterioration of soil quality due to build-up of chemical pollutants, and development of habitats for disease vectors such as mosquitoes and flies. Negative aspects have to be controlled, hopefully eliminated through wastewater treatment and irrigation practices and management to make it save wastewater reuse and really gain the related advantages (Mara and Cairncross, 1989; WHO, 1989; Pescod, 1992; Hespanhol, 1996; Westcot, 1997; Oron *et al*., 1999; Manel, 2001; Pereira *et al*., 2002; Choukr-Allah and Hamdy, 2004).

The control of water related diseases should be intimately related with water development, mainly in relation to wastewater reuse in irrigated agriculture. Malaria alone produces one million deaths annually. Engineering solutions to combat water vector diseases are required to be part of agricultural water management.

Particular care has to be oriented to control and eliminate pathogens in used wastewater and thus make it safe to workers and consumers. To be noted that health risks increase in areas where water supply and sanitation coverage is smaller since contamination risks increase. Problems are particularly acute in Africa and Asia, where raw or insufficiently treated wastewater is often used (Fig. 1).

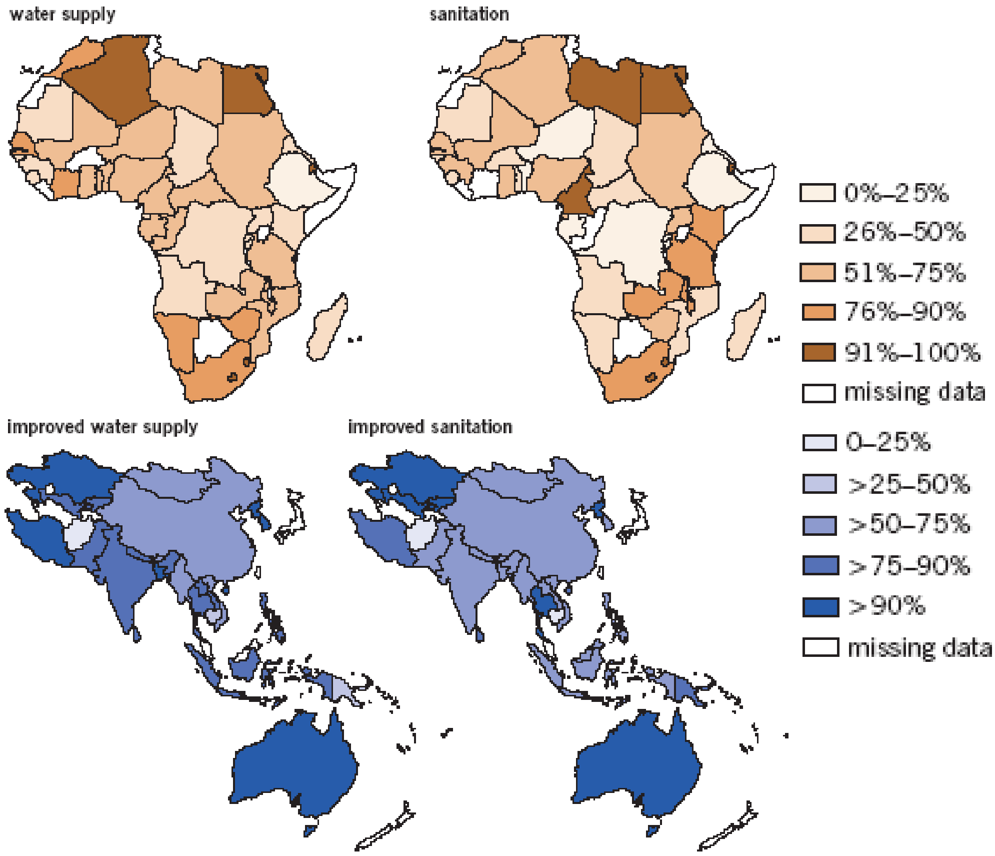

Figure 1. Coverage of improved water supply and sanitation in Africa and Asia (UNEP, 2003)

How safe may be the use of wastewater in irrigated agriculture is therefore a question to be raised before deciding the implementation of wastewater reuse programs. Safety for workers and customers shall be above other economic and physical issues.

To minimise the health risk from using wastewater in irrigation it is required:

- to recognize health risks due to wastewater
- to treat the wastewater to the level recommended
- to adopt appropriate irrigation methods
- to apply crop restrictions, which can be the most effective measure to protect the consumer, and
- to promote safe crop production areas supported by monitoring and control.

The paper discusses essential aspects along these lines aiming at effectively discussing and disseminating safe water reuse practices.

RECOGNIZING HEALTH RISKS: WASTEWATER AND EFFLUENT CHARACTERISTICS

The quality of irrigation water is of particular importance in arid zones where high rates of evaporation occur, with consequent salt accumulation in the soil profile. Thus, attention is often paid to risks relative to salinity impacts both relative to the crops and the soil as well as to the use of irrigation equipment in relation to the effect of dissolved solids (TDS) in the irrigation water. Many of the ions carried in the wastewaters are harmless or beneficial to crops at relatively low concentrations, but may become phytotoxic at high concentrations, or may negatively affect several metabolic processes. These aspects are generally well known and are not dealt herein.

Municipal wastewater is mainly comprised of water with relatively small concentrations of suspended and dissolved organic and inorganic solids. Organic substances include carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. In arid and semi-arid countries, water use is often fairly low and sewage tends to be very strong, where per capita water use is only 90 l/day while 200 l/day is common in water abundant areas (Pescod, 1992; Al-Nakshabandi *et al*., 1997). Municipal wastewater also contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements, including heavy metals, such as arsenic, cadmium, chromium, copper, lead, mercury and zinc. This water might also be at phytotoxic levels, which would limit its use in agriculture. Considering the possible accumulation of certain toxic elements in plants (e.g., cadmium and selenium), the intake of toxic materials through eating the crops irrigated with contaminated wastewater must be carefully assessed.

From the point of view of health, the contaminants of greatest concern are the pathogenic micro- and macro-organisms. Pathogenic viruses, bacteria, protozoa and helminths may be present in raw municipal wastewater and will survive in the environment for long periods. Pathogenic bacteria are generally present in wastewater at much lower levels than the coliform group of bacteria, which are easy to identify. Pathogenic organisms give rise to the greatest health concern in the use of wastewaters. In areas of the World where helminthic diseases caused by *Ascaris* and *Trichuris* spp. are endemic in the population and where raw untreated sewage is used to irrigate salad crops and/or vegetables eaten uncooked, transmission of these infections is likely to occur through the consumption of such crops. Further evidence was provided to show that cholera can be transmitted through the same channel. There is also evidence that cattle grazing on fields freshly irrigated with raw wastewater, or drinking from raw wastewater canals or ponds, can become heavily infected with the cysticerosis disease. Indian studies have shown that sewage farm workers exposed to raw wastewater in areas where *Ancylostoma* (hookworm) and *Ascaris* (nematode) infections are endemic have significantly higher levels of infection than other agricultural workers (cf. Mara and Cairncross, 1989)

In respect of the health impact of use of wastewater in irrigation, pathogenic agents are ranked as shown in Table 1. However, negative health effects were only detected in association with the use of raw or poorly treated wastewater, while inconclusive evidence suggested that appropriate wastewater treatment could provide a high level of health protection (Pescod, 1992). Risks from diseases such as schistosomiasis, clonorchiasis, and taeniasis vary from high to nil depending on local circumstances (WHO, 1989).

Table 1. Relative health impact of pathogenic agents

Risk	Agents
High risk (high incidence of excess infection)	Helminths (Ancylostoma, Ascaris, Trichuris and Taenia)
Medium Risk (medium incidence of excess infection)	Enteric bacteria (Vibrio cholera, Salmonella typhosa, Shigella)
Low Risk (low incidence of excess infection)	Enteric viruses (Viral diarrhoeas, hepathitis A)

Pescod, 1992; Pereira *et al*., 2002

The main microbiological parameters relative to wastewater that are particularly important from the health point of view are summarized in Table 2 (Pescod, 1992; Mara and Cairncross, 1989).

Table 2. Main pathogenic parameters relative to wastewaters

Pathogens	Survival time	Presence in wastewater
Coliforms & faecal coliforms *Citrobacter, Enterobacter, Klebsiella, Escherichia coli*	up to 60 days in water and 70 days in the soil	E. coli count is a main indicator
Faecal Streptococci *S. bovis, S. equines, S. faecalis*		occur both in man and in other animals
Clostridium perfringens	survival characteristics similar to viruses or even helminth eggs	useful in wastewater quality reuse studies
Salmonella spp S. typhi agent for typhoid	if removal of Salmonellae is achieved Shigellae and Vibrio cholera are probably also removed	typical in a tropical urban sewage
Enteroviruses Poliomyelitis and Meningitis, and respiratory infections	may attain 120 days in water	especially under tropical conditions
Rotaviruses gastro-intestinal problems	more persistent than enteroviruses	removal in parallel with that of SS, virus are solids-associated
Intestinal Nematodes *Ascaris lumbricoides*	several months	infections can be spread by effluent reuse practices

Source: adapted from Mara and Cairncross, 1989; Pescod, 1992; Pereira *et al*., 2002

Several studies by IWMI in Pakistan (Feenstra *et al*, 2000; Hussain *et al*., 2002; Ensink *et al*., 2002) and Mexico (Scott *et al*., 2000) evidence the pertinence of considerations above since results show that a large percentage of workers and other, particularly children in areas using untreated wastewater are exposed and contaminated by wastewater vector diseases (e.g., Fig. 2).

Risks of exposure to pathogens in wastewaters depend on several factors and should be differentiate relative to workers, consumers and handlers of the agricultural products. Risks for workers mainly depend upon the irrigation method and, of course, the quality of wastewater. Risks for consumers depend upon the type of product, how food products are consumed, and degree of contact of wastewater with the product (Table 3).

To control health risks for the consumer, wastewater reuse standards are required in relation to the existing risks in the area under consideration, i.e. standards should guide relative to practices of irrigation, crop production, products handling, etc. but not as standards for treatment requirements. Standards are very diverse from country to country and sometimes inside the same country. Reviews on these standards are presented by several authors, e.g., Lazarova (2000) and Somaratne and Ahmed (2000). Most commonly, standards are based upon those proposed by the World Health Organization (WHO, 1989; Pereira *et al*., 2002).

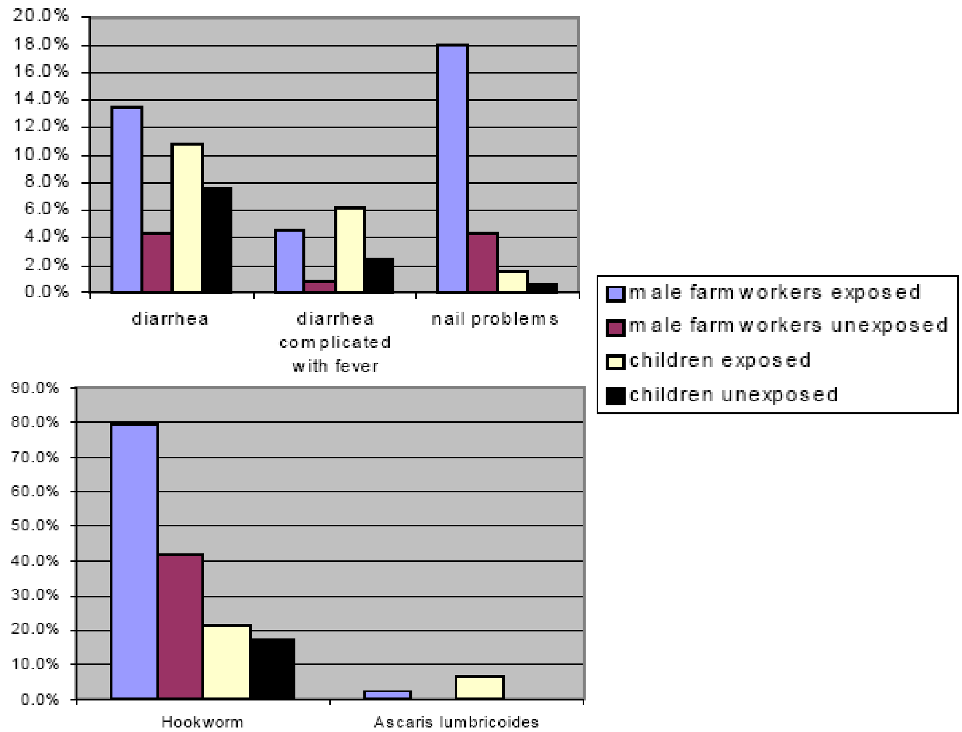

Figure 2. Exposure and contamination of workers and children due to use of wastewater in irrigation in Southern Punjab, Pakistan (Feenstra *et al.*, 2000)

Table 3. Health risks in relation to wastewater use in crops' irrigation

Risk	Target	Crops
Lowest	Consumer (field worker protection is needed)	• Crops not for human consumption (fiber crops). • Crops normally processed by heat or drying before human consumption (e.g. grains, oilseeds, sugar beet). • Vegetables and fruits grown exclusively for canning or other processing that effectively destroy pathogens. • Fodder crops and animal feed crops that are sun-dried and harvested before consumption by animals (hay, silage).
Increased	Consumer, field worker and handler	• Pasture, green fodder crops. • Crops for human consumption that do not come into direct contact with wastewater (fruits not picked off the ground; sprinkler/ spray irrigation not used (tree crops, vineyards). • Crops for human consumption normally eaten only after cooking (e.g. potatoes, eggplant, beetroot). • Crops for human consumption, the peel of which is not eaten (e.g. melons, citrus fruits, bananas, nuts, groundnuts). • Any crop not identified as high-risk when sprinkler irrigation is used.
Highest	Consumer, field worker and handler	• Any crops eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruits). • Landscape irrigation with public access (parks, lawns, golf courses).

Source: Pereira *et al.*, 2002

WASTEWATER TREATMENT AND RECOMMENDED LEVELS

Wastewater treatment aims at safe disposal of human and industrial effluents, without danger to human health or damage to the natural environment. Irrigation with wastewater is both disposal and utilisation. Some degree of treatment needs to be provided to raw municipal wastewater before it can be used for agricultural and landscape irrigation, aquaculture or other uses. The required quality of effluent will depend on the proposed water uses, crops to be irrigated, soil conditions and the irrigation system (Pereira *et al*., 2002).

The most appropriate wastewater treatment for agricultural uses is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements. A summary describing the objectives of different degrees of treatment is given in Table 4. Adopting as low a level of treatment as possible while achieving the desired results is important, especially in developing countries. In practice, it may be better to design the reuse system to accept a low-grade of effluent rather than to rely on advanced treatment processes to produce a reclaimed effluent which continuously meets a stringent quality standard.

The design of wastewater treatment plants is usually based on the need to reduce organic and suspended solids loads to limit pollution of the environment. Pathogen removal has very rarely been considered an objective but, for reuse of effluents in agriculture, this must be of primary concern. Treatment to remove wastewater constituents that may be toxic or harmful to crops, aquatic plants and fish is normally not economically feasible. However, the removal of toxic elements and pathogens that may affect human health needs to be considered.

Table 4. Wastewater treatment degrees and objectives

Treatment degrees	Objectives
Preliminary	Removal of coarse solids
Primary	Removal of settable organic and inorganic solids. Large fractions of BOD5, total suspended solids, oil and grease are removed but not colloidal and dissolved constituents
Secondary	Further treatment of the primary effluent to remove the residual organics and suspended solids. In most cases, involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological processes. When coupled with a disinfection step such as chlorination, these processes can provide substantial but not complete removal of bacteria and viruses
Tertiary and/or advanced	When specific undesirable wastewater constituents cannot be removed by secondary treatment (N, P, additional suspended solids, refractory organics, heavy metals and dissolved solids)
Disinfection	Chlorination, ozonation, ultra violet irradiation (UV), periacetic acid (PAA), membrane filtration (MF), or ultra filtration (UF) for virus free effluents

Source: adapted from Pereira *et al*., 2002

As shown in Table 5, the great challenge in selecting a treatment system results from the relation among the efficiency in removing pathogens and the economic and managerial factors. Systems that are efficient in removing helminths or virus are generally those which have higher cost and more demanding operation and maintenance (Table 5). When comparing disinfection systems something similar occurs: higher efficiency in removing pathogens, including the avoidance of residual toxicity and bacterial regrowth potential, generally implies higher costs (Table 6).

Table 5. Qualitative comparison of various treatment systems

Criteria	Factor considered	Package plant	Activated sludge plant	Extended aeration activated sludge	Biological filter	Oxidation ditch	Aerated lagoon	Waste stabilisation pond system
Plant performance	BOD removal	F	F	F	F	G	G	G
	FC removal	P	P	F	P	F	G	G
	SS removal	F	G	G	G	G	F	F
	Helminth removal	P	F	P	P	F	F	G
	Virus removal	P	F	P	P	F	G	G
Economic factors	Simple and cheap	L	L	L	L	M	M	H
	Simple operation	L	L	L	M	M	L	H
	Land requirement	H	H	H	H	H	M	L
	Maintenance cost	L	L	L	M	L	L	H
	Energy demand	L	L	L	M	L	L	H
	Sludge removal cost	L	M	M	M	L	M	H

Source: adapted from Westcot, 1997

BOD – biochemical oxygen demand; FC – faecal coliform; SS – total suspended solids.
G – good; F – fair; P – poor.
H – high; M – medium; L – low (e.g. low demanding or low cost).

Table 6. Qualitative comparison of various disinfection technologies

Characteristics	Chlorine	PAA	Ozone	UV	MF	UF
Bacterial action	++	++	+++	++	+++	+++
Virucidal action	++	+	+++	+	none	+++
Bacterial regrowth potential	+	+++	++	+	none	none
Residual toxicity	+++	++	+	none	none	none
By-products	+++	none	+	none	none	none
Operating costs	+	++	++	++	+++	+++
Investment costs	+	+	+++	++	+++	+++

Source: Lazarova, 2000

"+" low; "++" middle; "+++" high.

This simplified analysis of treatment and disinfection problems shows that the safe reuse of wastewater in irrigation should not depend upon the treatment technologies but on irrigation, crop and products management that make the use of wastewater safe for consumers and workers. To adopt stringent water quality guidelines and corresponding treatment and disinfection technologies leads to safety but may be prohibitive for users in developing countries. If guideline requirements are above existing conditions for their adoption then health problems cannot be adequately solved. Thus it may be better to adopt less expensive, easy to manage technologies that produce treated wastewaters which may be more safely used when enforcing the adoption of appropriate irrigation methods and crop restrictions, which can be the most effective measure to protect the consumer, as well as promoting safe crop production areas.

MINIMISING HEALTH HAZARDS IN WASTEWATER IRRIGATION PRACTICES

A potential for disease transmission exists when wastewater is used for irrigation, because pathogens brought with the wastewater can survive for many days in the soil or on the crop. Factors influencing transmission of disease include the degree of wastewater treatment, the crops grown, the irrigation method used to apply the wastewater, and the cultural and harvesting practices used.

The possible infection of field workers results from direct contact with the crop or soil in the area where wastewater is used. This path is directly related to the level of protection needed for field workers. The only feasible means of dealing with the worker safety problem is to adopt preventive measures against infection. The following risk situations for field workers are often identified (Westcot, 1997):

- Low risk of infection
  - ❖ Mechanised cropping practices
  - ❖ Mechanised harvesting practices
  - ❖ Irrigation ceasing long before harvesting
  - ❖ Long dry periods between irrigations
- High risk of infection
  - ❖ High wind and dust areas
  - ❖ Hand cultivation and hand harvesting
  - ❖ Moving of sprinkler or other irrigation equipment
  - ❖ Direct contact with irrigation water

To minimise health hazards for field workers preventive measures are required. These include wearing protective clothing, including impermeable boots that prevent any direct skin contact with the wastewater, the maintenance of high levels of hygiene, and immunisation against infections likely to occur.

International guidelines or standards for the microbiological quality of irrigation water used on a particular crop do not exist. Because there is a lack of direct epidemiological data, the standards and guidelines for the quality of wastewater used for irrigation are focused on effluent standards at the wastewater treatment plant, rather than at the point of use. These standards are most often used for process control at wastewater treatment plants. WHO adopted the water quality guidelines for wastewater use in agriculture shown in Table 7.

Table 7. Recommended microbiological quality standards for wastewater use in irrigation(1)

Category	Reuse condition	Exposed group	Intestinal nematodes(2) (arithmetic mean no. of eggs/litre)(3)	Fecal coliforms (geometric mean no. per 100 ml)(3)	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields and public parks(4)	Workers, consumers, public	≤ 1	≤ 1000(4)	A series of stabilisation ponds designed to achieve the microbiological standard indicated or equivalent treatment
B	Irrigation of cereal crops, crops for industrial processing, fodder crops, pastures and tree crops(5)	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localised irrigation (drip or subsurface irrigation) of crops in category B if exposure of workers and public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology but not less than primary sedimentation

Source: WHO, 1989

(1) Guidelines may be modified following local epidemiological, socio-cultural and environmental studies
(2) *Ascaris* and *Trichuris* spp. and hookworms
(3) During the irrigation period
(4) To be reduced to 200 FC/100 ml for public lawns where the public may be in direct contact
(5) For fruit trees, irrigation should stop two weeks before fruits are harvested and no fruits should be picked from the ground. Sprinkler or spray irrigation should not be used.

These guidelines recommend less stringent values for faecal coliforms than were previously recommended, but are stricter than previous standards concerning the need to reduce helminth egg concentrations in effluent. It was implied that if the recommended helminth egg limit could be reached, that equally high removals of all protozoa would be achieved The purpose of applying the helminth standard throughout all cropping systems was to increase the level of protection for agricultural workers, who are at high risk from intestinal nematode infection (Mara and Cairncross, 1989).

The guidelines in Table 7 are for the microbiological quality of treated effluent from a wastewater plant when that water is intended for irrigation but they are not intended as standards for quality monitoring of irrigation water (Mara and Cairncross, 1989). However, because urban populations grow enormously, the degree of river and irrigation water supply contamination in developing countries will likely increase. Pressure will also increase to use partially treated wastewater for irrigation until adequate treatment facilities can be constructed. Thus, there is an immediate need to control wastewater use in high risk cropping systems such as vegetable crop production. Since guidelines or regulations that define the quality of water that can be safely applied to irrigation do not exist, the guidelines of WHO could be used as irrigation water standards for regulating cropping practices. These guidelines could be applied in areas where wastewater is utilised directly for irrigation or where use is indirect by diversion of contaminated river water supplies.

Using the guidelines as irrigation standards would help to (Pereira *et al*., 2002):

(a) Assess the extent of contamination.
(b) Reduce the disease infection risk until suitable wastewater treatment is adopted.
(c) Improve the basic health level in rural areas.
(d) Provide data that can be used in planning for wastewater management.

Irrigation practices should be designed according to the quality of wastewater being used. The selection of methods of irrigation with wastewater to comply with guidelines for controlling health risks is described in Table 8.

Table 8. Adequateness of irrigation methods for wastewater use

Irrigation methods	Human contact (health hazard)	Contact with fruits and harvestable yield (contamination hazard)	Salt accumulation in the root zone (salinity hazard)	Foliar contact (toxicity hazard)
Basin irrigation and border irrigation	Likely to occur, mainly when water is controlled manually. Preventive measures including clothing requirements	Not occurring for tree crops and vines, and most horticultural and field crops. May occur for low vegetable crops such as lettuce and melon	Not likely to occur except for the under-irrigated parts of the field when uniformity of water application is very poor	Possible for bottom leaves in low crops (e.g. lettuce, melon) and fodder crops. Possible during first stage of growth of annual crops
Corrugated basin irrigation	Likely to occur when water is controlled manually, less when automation is adopted. Preventive measures including clothing are required	Not likely to occur because crops are grown on ridges	Salts tend to accumulate on the top of the ridge. Leaching prior to seeding or planting is required for assuring germination and plant establishment	Exceptionally because crops are grown on ridges and water flows in furrows between them
Furrow irrigation	Likely to occur, when water is controlled manually, less when automation is adopted	Not likely to occur because crops are grown on ridges	Salts accumulate on the top of the ridge. Leaching is required prior to seeding/planting	Exceptionally because crops are grown on ridges
Sprinkler irrigation	Generally workers are not in the field when irrigating but they may have contact with wetted equipment. Small drops into the air should be avoided	Fruits and harvestable yield are contaminated	Not likely to occur except for the under-irrigated parts of the field resulting from low uniformity of water application	Severe leaf damage can occur affecting yields
Micro irrigation: Drip and subsurface irrigation	Not likely to occur except contact with wetted irrigation equipment	Not likely to occur	Not likely to occur except for the under-irrigated parts of the field due to low uniformity of water application	Not likely to occur
Micro irrigation: Micro-sprinkling and microspray	Generally workers are not in the field when irrigating but they may have contact with wetted equipment. Small drops into the air should be avoided	Fruits and harvestable yield of vegetable crops may be contaminated. Less likely for under-tree irrigation with no wind	Not likely to occur except for the under-irrigated parts of the field resulting from low uniformity of water application	Severe leaf damage can occur definitely affecting yields of annual crops but not for irrigation of trees and vines if drops are large enough and jets are undertree.

Source: Pereira *et al.*, 2002

Aspects considered for evaluating the adequateness of irrigation methods to the application of wastewaters mainly concern:

- the probability of direct contact of workers with the irrigation water; which refers to the need for adopting more stringent preventive measures as referred above when that contact is likely to occur;
- the direct contact of the water with the harvestable yield that implies the need for more care on consumer protection measures, which relates to the contamination potential of the water, the type of product and way how it is consumed, so with the potential contamination hazards for the consumers and other agents, which refer to guidelines in Table 7;
- the foliar contact with the water that may cause phytotoxic problems to the crop, which depends upon the type and concentration of toxic ions in the water;
- the capability for avoiding salt accumulation in the crop root zone, which would cause soil degradation. This is controlled by leaching of the salts from the root zone naturally when rainfall is

abundant, or by applying a leaching fraction with the irrigation water. The appropriate application of a leaching fraction depends on the irrigation method and the performance of the irrigation system. Practising over-irrigation to be sure that salts are leached produces excessive percolation to the groundwater and its quality can be degraded, so drainage has to be considered. However, problems may be controlled easily if the irrigation system is designed carefully allowing for control of volumes applied and for an even distribution of water over the field.

Summarising, the safe use of wastewater in irrigation requires not only compliance with guidelines for the control of health risks, but also well designed and efficient irrigation systems. Case study examples are provided in the literature (e.g. Oron *et al*., 1999, Loudon, 2001) and to this Workshop.

MINIMISING HEALTH HAZARDS: CROP RESTRICTIONS

To minimise the health risk from using wastewater in irrigation, the prime approach is to treat the wastewater to the level recommended. However, as discussed above, the reality is that untreated or insufficiently treated wastewaters are often used for irrigation.

The application of crop restrictions can be the most effective measure to protect the consumer. In fact, crop restrictions constitute the most widely used measure to protect public health. Crop restrictions focus primly on salad or vegetable crops that are normally eaten raw as indicated before (Table 7).

Crop restrictions need a strong institutional framework and the capacity to monitor and control compliance with the regulations. The following factors favour the adoption of crop restrictions (Mara and Cairncross, 1989):

- a law-abiding society or strong law enforcement;
- allocation of wastewater is controlled by a public body that has legal authority to enforce crop restrictions;
- the irrigation water conveyance and distribution system is controlled by strong central management;
- there is high demand and price advantage for the unrestricted crops;
- there is little market pressure in favour of the excluded crops; and
- wastewater is used by a small number of large farms.

Very large, dispersed irrigation schemes and those having poor or weak management make it difficult to enforce crop restrictions. Difficulties also occur when producers are mainly small farmers and the market prices do not favour the adoption of lower risk crops.

In many developing countries, wastewater, including untreated effluent, is discharged directly to surface waters and these are diverted downstream for irrigation purposes. This leads to widespread distribution of the wastewater and makes crop restriction extremely difficult (Fig. 3).

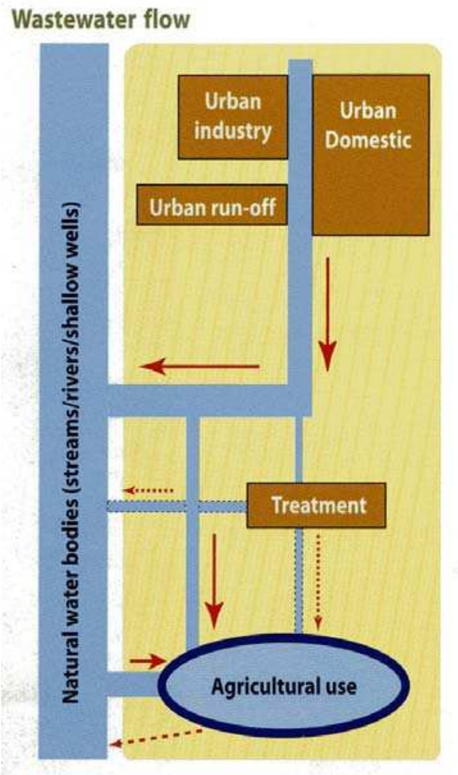

Figure 3. Uncontrolled wastewater flow paths (IWMI, 2003)

MONITORING AND CONTROL AND PROMOTION OF SAFE CROP PRODUCTION AREAS

Difficulties for application of the WHO guidelines (Table 7) in monitoring may result from the lack experience in monitoring helminth egg concentrations in irrigation water and insufficiency of techniques available. Therefore, monitoring may focus on the faecal coliform guidelines, for which techniques are available and quite widely used.

Developing a program to promote safe crop production areas should occur alongside and as an alternative to crop restrictions. However, this approach is only feasible for areas where a good control of used waters exist, where the technological level of farming and irrigation management is high and for countries and regions where the social attitude relative to water favours the implementation of relatively expensive and stringent programs Areas such in Fig. 3 cannot be considered.

Promoting safe crop production areas can be achieved with a three-phased process (see Westcot, 1997). The first phase is to develop a sound water quality monitoring program that is used to evaluate the existing levels of contamination in the water being used. This includes selection of contamination indicators, establishing field-sampling methods, defining laboratory methods and participating laboratories, selecting field monitoring sites, and then conducting a field water quality monitoring program. The second phase consists of evaluating the water quality data and developing procedures to assess the levels of contamination. The resulting database can be used to define safe production areas and as a basis to control or regulate contaminated water use in vegetable or other high-risk areas. The third phase is developing mechanisms to regulate the use of potentially contaminated water on high-risks crops, so leading to certification programs.

a. Monitoring and development of an information database

The goal of a water quality monitoring program is to determine spatially how extensive is the contamination of irrigation water and at what level. Results must provide the Authorities with a sound basis for any required follow-up action. The procedure and parameters used for measurement must have national and international recognition and be applicable to the entire country. The following steps should be considered:

- Selection of observation areas and sites. This may be performed by considering, among others the availability of data on water quality and water vector diseases; the location of major vegetable and high-risk crop production areas; the location of major population centres; information characterising the irrigation system, the irrigation methods and crop production practices; the location and capacity of laboratory facilities and resources available for conducting the sampling and laboratory analyses.
- Selection of the water quality indicators, which should be applicable to several diseases and include those for helminth eggs and bacteria, namely the faecal coliform; recognised at national and international levels; used for routine testing and using analytical procedures well known in national laboratories, and able to provide a basis for establishing guidelines and regulations.
- Choice of analytical methods, which should be reliable, cost effective and well known from national laboratories, and have international acceptance.
- Selection of laboratories, in terms of certified quality, knowledge on procedures to be used, and distance to the monitored areas.
- Selection of sampling techniques, including number and frequency of samples, which depend upon the objectives of monitoring indicators selected, and resources available.
- Selection of field sites. These depend upon water sources in the irrigated area; location of contaminant inputs, - occurring prior to the canal supply or within the irrigation system (primary and secondary contamination, respectively), and crop patterns and cropping and irrigation practices.

b. Data assembling and implementation of a database.

Consideration should be given to existing data - geographical, physical, agronomic, irrigation, health and water quality data - as well as to sampling methods, analytical procedures and indicators to be included in the monitoring program.

c. Certification, regulation and other policy issues.

Certification may be considered for the quality of products and for the safety of production, which stimulates optimal practices by the farmers. Similarly, when water quality reaches a level where health hazards are not to be expected, certification can be given to the quality of the water.

Certification may be given to an irrigated area where standards are met, or to individual farmers.

Policy issues include:

- Benefits associated with certification.
- Regulations aiming at control of specified contaminants, promotion of improved health standards and irrigation practices.
- Policies on long-term wastewater use.

CONCLUSIONS

The analysis above shows that risks associated with wastewater use in irrigation may overcome benefits resulting from its use when appropriate measures and practices are not considered. This situation creates a challenge to wastewater users and promoters that is to implement appropriate measures to control disease vectors and produce safe conditions for workers and consumers.

First, it is necessary to better characterize the effluents used, including those treated, non-treated or insufficiently treated to define, select the users practices that minimize risks. It is not possible, mainly in poor farming areas, to adopt a treatment level that includes adequate disinfection of waters, so it is required to, at least recognize the associated risks. Once this are known, field irrigation and crop practices have to be adequate to the problem, both focusing the protection of the workers and respective families, children in particular, and the consumers.

A great effort needs to be developed to enforce crop restrictions, mainly relative to the crops to be eaten uncooked and associate crop restrictions with the control of wastewaters in canals and watercourses to avoid uncontrolled uses and uncontrolled contacts, including for bathing or animal drinking. In areas where better conditions exist, the promotion of safe production areas associated with a monitoring and control program may be a good alternative to crop restrictions and favour safety for consumers and the environment.

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