Risk assessment and management: Wastewater and reuse problems and case studies

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Content

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- Introduction: Use of treated waste water
- Risk for humans and the environment
  - Routes of exposure
  - WHO Guidelines 2006
- Risk reduction measures

How can treated wastewater be reused?

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- Urban water reuse (unrestricted & restricted) (e.g. toilet flushing)
- Agricultural irrigation (food & nonfood crops) (unrestricted & restricted)
- Recreational water use (unrestricted & restricted)

- Environmental water reuse (Wetlands restoration, stream augmentation, water impoundments for boating, wading, andswimming
- Industrial water reuse (e.g. cooling water)
- Groundwater recharge
- Indirect potable reuse

Water-related diseases in developing countries

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- Half the people in the developing world are suffering from **one or more of the main diseases** : diarrhea, ascaris, dracunculiasis (guinea worm), hookworm, schistosomiasis (bilharzias, or snail fever) and trachoma.
- Approximately 4 billion cases of **diarrhea** each year cause 2.2 million deaths, mostly among children under five
- **Intestinal worms** infect about ten percent of the population of developing countries;
- Worldwide, over 2 billion people are infected with **schistosomiasis** and soil-transmitted helminthes, of whom 300 million suffer serious illness;
- **Arsenic** in drinking water is a major public health threat. In Asia, more than 50 million people per year drink arsenic-contaminated water.

“Five F’s” in water and sanitation

Fluid - drinking contaminated water and having too little water to wash – (waterborne fecal-oral diseases like cholera, typhoid, diarrhea, viral hepatitis A, dysentery and dracunculiasis (guinea worm disease)).

Feces - contamination of water, soil and food with human fecal matter

Fingers - unwashed hands preparing food or going into the mouth

Food - eating contaminated food

Flies - spreading disease from feces to food and water or directly to people

Harmonized approach to risk assessment
(Stockholm Framework (WHO,2001))

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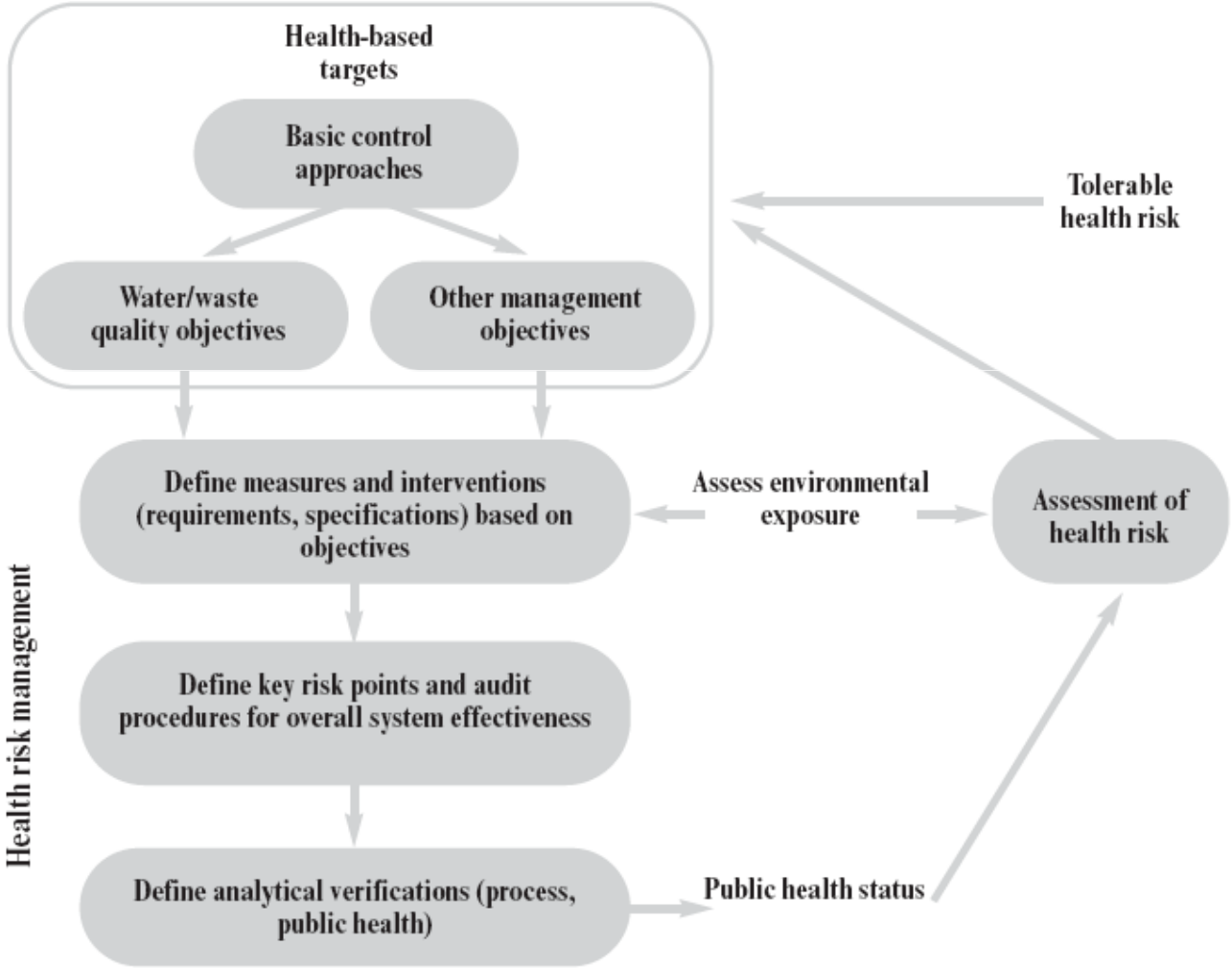

Excreated organism concentrations in WW (WHO, 2006)

Organism	Numbers in wastewater (per litre)
Bacteria	
Thermotolerant coliforms	10^8–10^{10}
Campylobacter jejuni	10–10^4
Salmonella spp.	1–10^5
Shigella spp.	10–10^4
Vibrio cholerae	10^2–10^5
Helminths	
Ascaris lumbricoides	1–10^3
Ancylostoma duodenale / *Necator americanus*	1–10^3
Trichuris trichiura	1–10^2
Schistosoma mansoni	ND
Protozoa	
Cryptosporidium parvum	1–10^4
Entamoeba histolytica	1–10^2
Giardia intestinalis	10^2–10^5
Viruses	
Enteric viruses	10^5–10^6
Rotavirus	10^2–10^5

ND, no data
Sources: Feachem et al. (1983); Mara & Silva (1986); Oragui et al. (1987); Yates & Gerba (1998).

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Exposure route:
Contact/consumption

Relative importance:
Low – high

Routes of Transmission/Exposure to Pathogens or Contaminants

People at risk:

Consumers

- **Consumption of contaminated products**
- **Consumption of drinking water contaminated due to wastewater use activities**
- **Consumption of animals or animal products contaminated due to wastewater exposure**

Exposure & Burden of Disease

People at risk:

Farm workers and their families
Nearby communities

- Human contact **with wastewater or contaminated crops**
- Inhalation
- Vector borne disease transmission **resulting from the development and management of wastewater irrigation schemes**

WHO Guideline (2006) on reuse of human excreta

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are built on…

the **assessment and management** of health risks associated with wastewater use through the application of various health protection measures during all steps of wastewater use and until it reaches the consumer.

because…

the consumer have a right to demand safe food.

Tolerable health risk (WHO, 2004)

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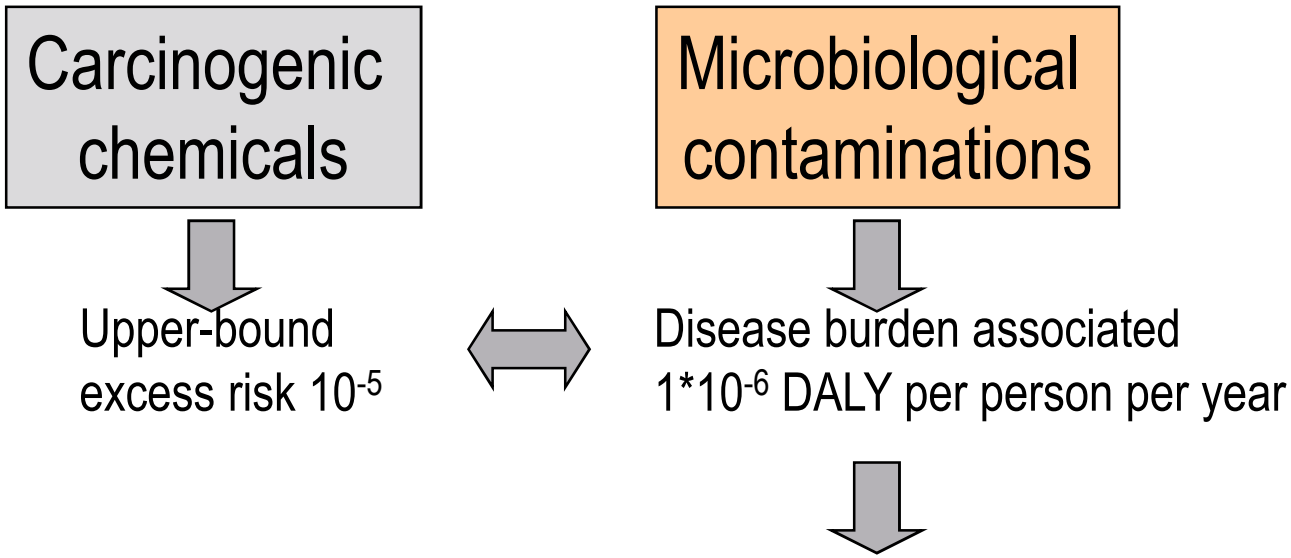

DALY = Disability adjusted life years
(WHO, 2004)

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The disability adjusted life year (DALY) is a composite measure of years of life lost because of premature mortality and equivalent years lost because of lower 'quality of life' as a result of serious injury and disability.

DALY = Severity of health effects * duration * number of people affected

0 (normal good health) ……. 1 (death).

DALY = years of life lost by premature mortality (YLL) and years of healthy life lost in states of less than full health, i.e., years lived with a disability (YLD)

DALY = YLL + YLD

Definition of the tolerable risk

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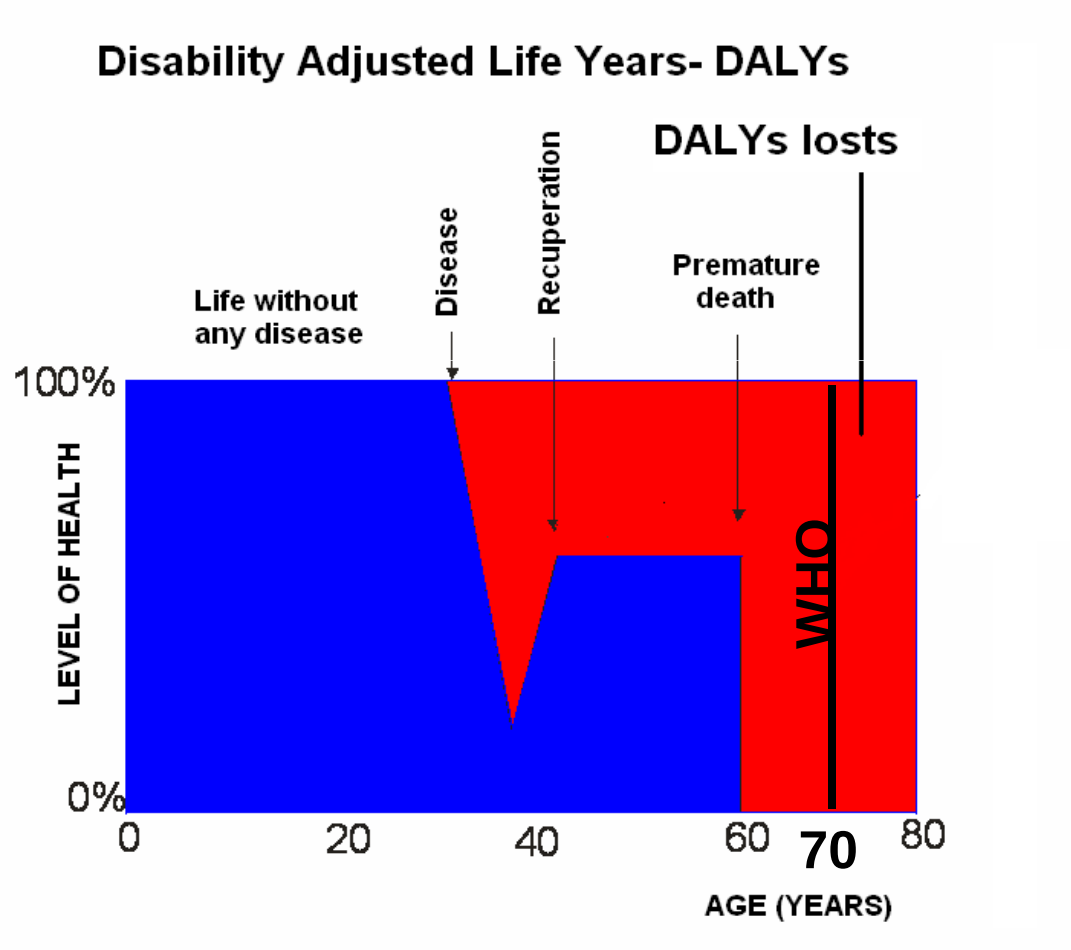

To standardize the acceptable risk caused by different agents in different norms (Drinking water a risk of 10^{-5} for cancer while in irrigation a risk of 10^{-3} for diarrheas)

How do WHO Guidelines protect people?

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Health based target can be reached when:

- all protection measures result in pathogens reduction 6-7 log units.
- viral reduction of 6-7 Log units, is applicable by default to bacterial and protozoal pathogens
- **In addition** to Helminthes eggs reduction to achieve ≤ 1egg/l

Verification by monitoring of E. coli or thermotolerant coli $< 10^0 - 10^1$*/100ml*

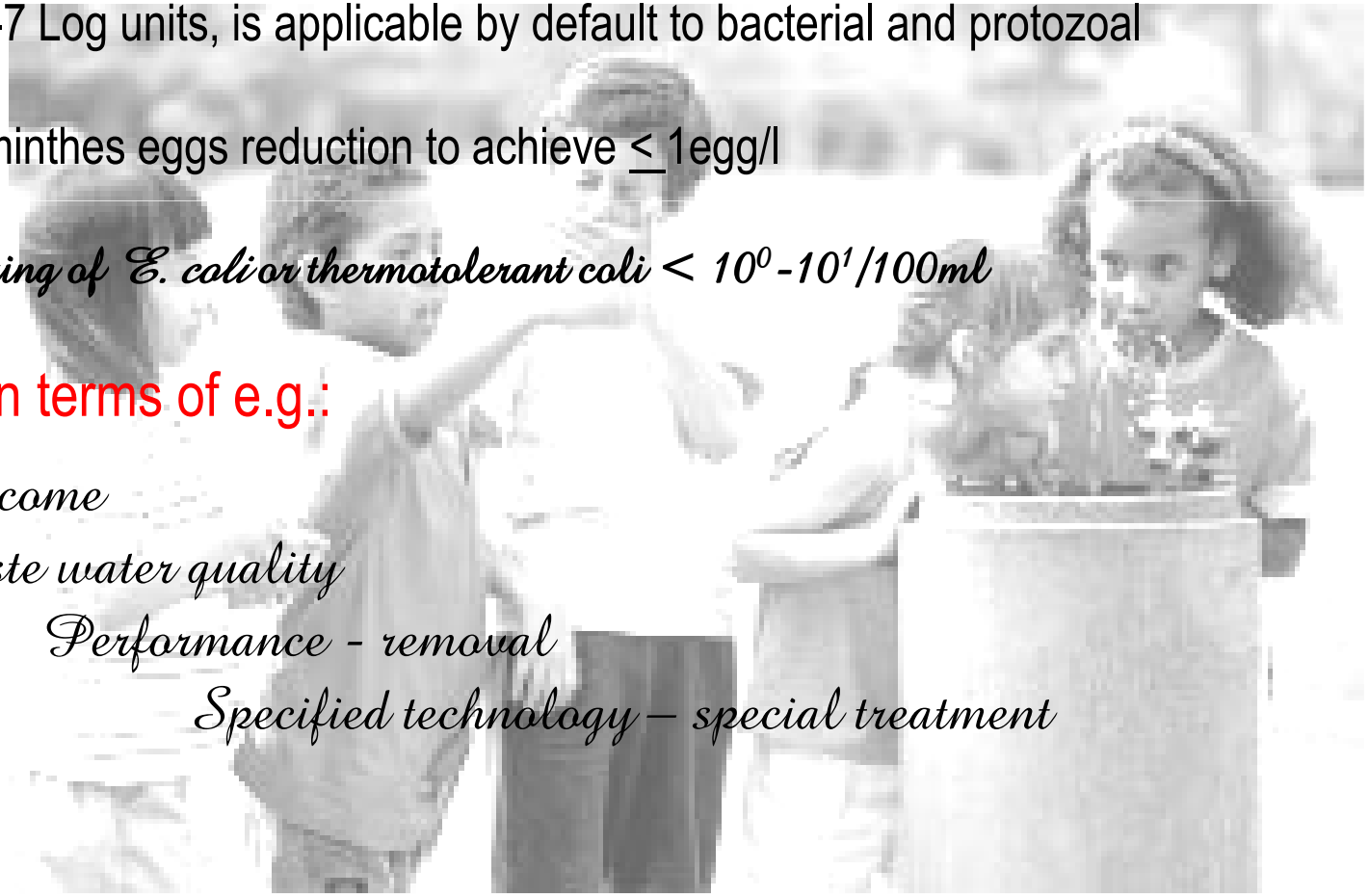
Can be specified in terms of e.g.:

Health outcome

Waste water quality

Performance - removal

Specified technology – special treatment



6 -7 log reduction

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- 90 % reduction 1 log
- 99 % reduction 2 logs
- 99.9 % reduction 3 logs
- 99.99 % reduction 4 logs
- 99.999 % reduction 5 logs
- 99.9999 % reduction 6 logs
- 99.99999 % reduction 7 logs

log 6 reduction:

- 100 000 000 (10^8 thermotolerant coliforms) will be reduced to 100 (10^2)

Ranges for Pathogen Reduction by Various Health Protection Measures

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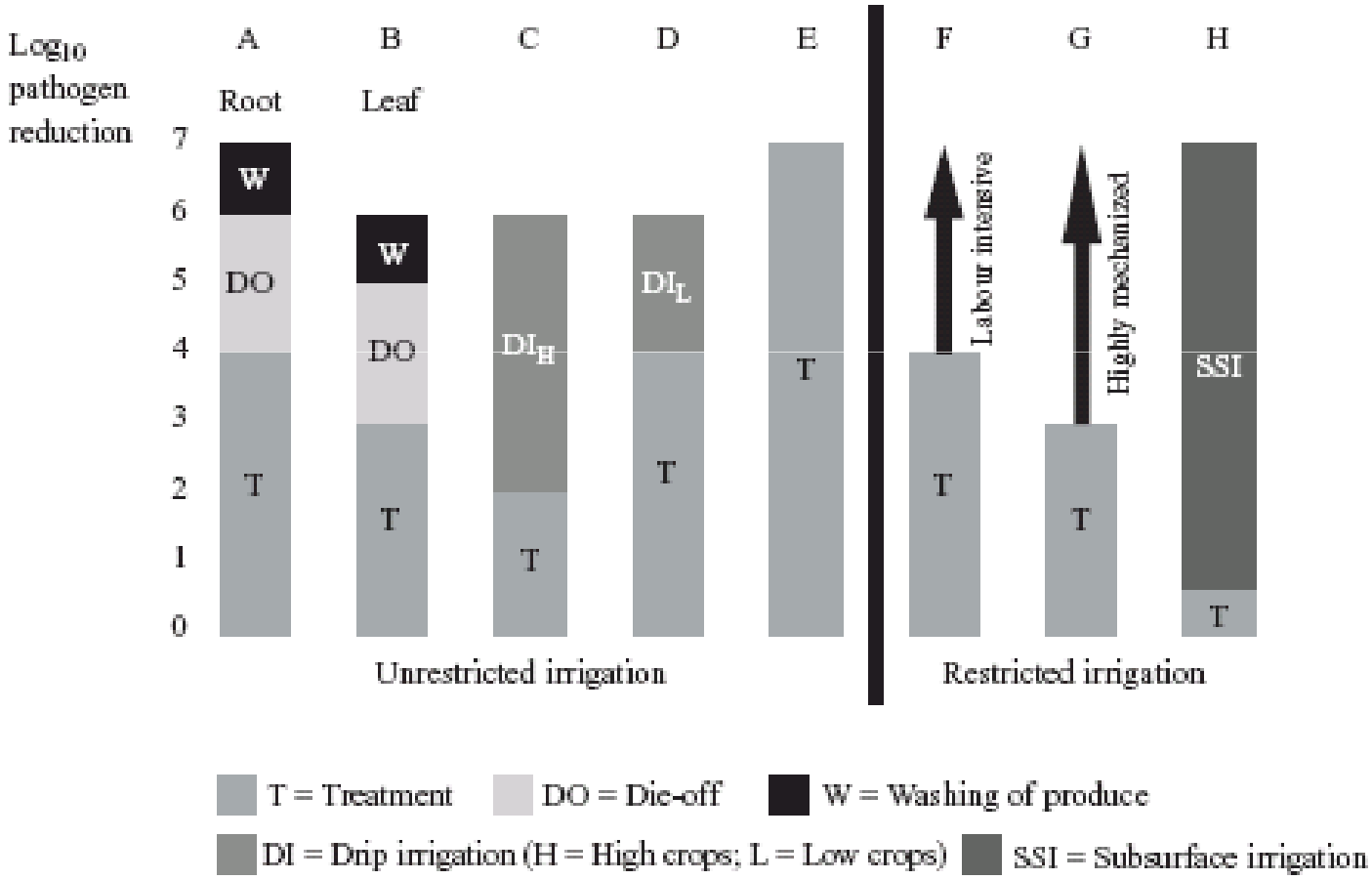
Treatment	1-6 log units
Drip irrigation (Low growing crops, (LGC)	2 log units
Drip irrigation (high growing crops, (HGC)	4 log units
Spray irrigation	1 log units
Spray buffer zone	1 log units
Pathogen die off	0.5-2.0 log units
Produce Washing	1 log units
Produce peeling	2 log units
Produce cooking	6-7 log units
Produce disinfecting	2 log units

Combination of different health protection measures to achieve the health based target of 10^{-6} DALY's per person per year



Source: WHO guidelines for safe use of wastewater, excreta and grey water, 2006

Element/compound	Soil concentration (mg kg^{-1})	Organic compound	Soil concentration (mg kg^{-1})
Antimony	36	Dichlorobenzene	15
Arsenic	8	2,4–D	0.25
Barium*	302	DDT	1.54
Beryllium*	0.2	Dieldrin	0.17
Boron*	1.7	Dioxins	0.00012
Cadmium	4	Heptachlor	0.18
Fluorine	635	Hexachlorobenzene	1.40
Lead	84	Lindane	12
Mercury	7	Methoxychlor	4.27
Molybdenum	0.6	PCBs	0.89
Nickel	107	PAHs (as benzo(a)pyrene)	16
Selenium	6	Pentachlorophenol	14
Silver	3	Phthalate	13,733
Thallium*	0.3	Pyrene	
Vanadium*	47	Styrene	0.68
Aldrin	0.48	2,4,5–T	3.82
Benzene	0.14	Tetrachloroethane	1.25
Chlorodane	3	Tetrachloroethylene	0.54
Chlorobenzene	211	Toluene	12
Chloroform	0.47	Toxaphene	0.0013
		Trichloroethane	0.68

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Water quality for irrigation (WHO, 2006)

Parameter		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Salinity EC_w[a]		dS/m	<0.7	0.7–3.0	>3.0
TDS		mg/l	<450	450–2000	>2000
TSS		mg/l	<50	50–100	>100
SAR[b]	0–3	meq/l	>0.7 EC_w	0.7–0.2 EC_w	<0.2 EC_w
SAR	3–6	meq/l	>1.2 EC_w	1.2–0.3 EC_w	<0.3 EC_w
SAR	6–12	meq/l	>1.9 EC_w	1.9–0.5 EC_w	<0.5 EC_w
SAR	12–20	meq/l	>2.9 EC_w	2.9–1.3 EC_w	<1.3 EC_w
SAR	20–40	meq/l	>5.0 EC_w	5.0–2.9 EC_w	<2.9 EC_w
Sodium (Na^+)	Sprinkler irrigation	meq/l	<3	>3	
Sodium (Na^+)	Surface irrigation	meq/l	<3	3–9	>9
Chloride (Cl^-)	Sprinkler irrigation	meq/l	<3	>3	
Chloride (Cl^-)	Surface irrigation	meq/l	<4	4–10	>10

EC_w..Electrical conductivity in deciS/m (25°C

Water quality for irrigation (WHO, 2006)

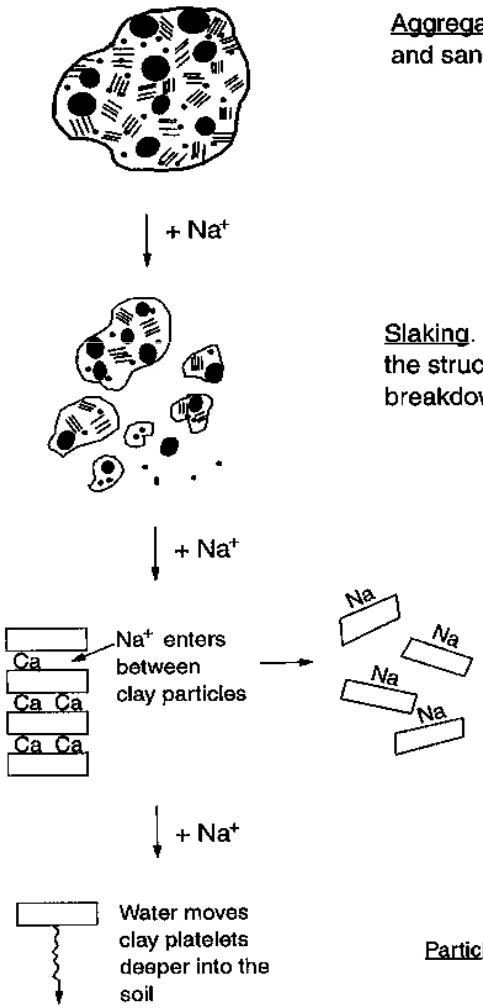
Parameter		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Chlorine (Cl_2)	Total residual	mg/l	<1	1–5	>5
Bicarbonate (HCO_3^-)		mg/l	<90	90–500	>500
Boron (B)		mg/l	<0.7	0.7–3.0	>3.0
Hydrogen sulfide (H_2S)		mg/l	<0.5	0.5–2.0	> 2.0
Iron (Fe)	Drip irrigation	mg/l	<0.1	0.1–1.5	>1.5
Manganese (Mn)	Drip irrigation	mg/l	<0.1	0.1–1.5	>1.5
Total nitrogen (TN)		mg/l	<5	5–30	>30
pH			Normal range 6.5–8		
Trace elements (see Table A1.2)					

Challenges of waste water use

- Increase in soil salinity
  - Residential use of water typically adds about 200-400 mg/L of dissolved salts with high Na content
  - Changes osmotic pressure at the root
  - Provokes specific ion toxicity (Cl, B or Na)
  - Interferes with uptake of essential nutrients (K, NO_3)
  - May destroy soil structure

Sodium Adsorption Ratio (SAR)

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}] + [Mg^{2+}]}{2}}}$$



Measures to cope with salinity

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Salinity	Avoid the use of water with 500–2000 mg TDS/l or 0.8–2.3 dS/m electrical conductivity, depending on the type of soil and land drainage
	Reduce upstream salt use and discharge into wastewater
Soil salinity and sodicity	Increase soil washing, improve ground drainage and/or apply soil amenders
	Dilute water with sodium adsorption ratio >8 and electrical conductivity >2.3 dS/m

Conclusions

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WHO Guidelines (2006) set standards and reduction goals for pathogens and chemical contaminants and give recommendations for reduction measures to achieve:

human health

and environmental health

Wastewater use in agriculture demands:

- monitoring and control of

  the treatment, the wastewater, the application and the product
- health protection measures
- hygiene education programs for farmers and local food handlers

for a continuous improvement to sustain and ensure **safe use of wastewater** in agriculture

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Thank you for your attention

Third edition of the WHO
Guidelines for the safe use of wastewater, excreta and greywater, 2006