SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

SWIM-H2020 SM Regional

Training on Technical, Regulatory and Cultural Aspects of Treated Wastewater Reuse (REG-8)

Presented by:

Mr. Rifaat ABDEL WAHAAB, PhD, NKE - Wastewater Reuse

Module 2. Strengthening and Updating of Knowledge on New Developments of Wastewater Reuse Guidelines

Guidelines & Health Risk Management

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Presentation Outline

I. Wastewater Reuse ▬ Background & Context
II. Benefits & Risks of Wastewater Use
III. Guidelines & Standards (WHO,FAO & USEPA)
IV. Health Protection Measures –Multi-Barrier Approach
V. Emerging Contaminants
VI. Pilot Study – Fate of pathogens in crops irrigated with TWW (South Cairo)

Background & Context

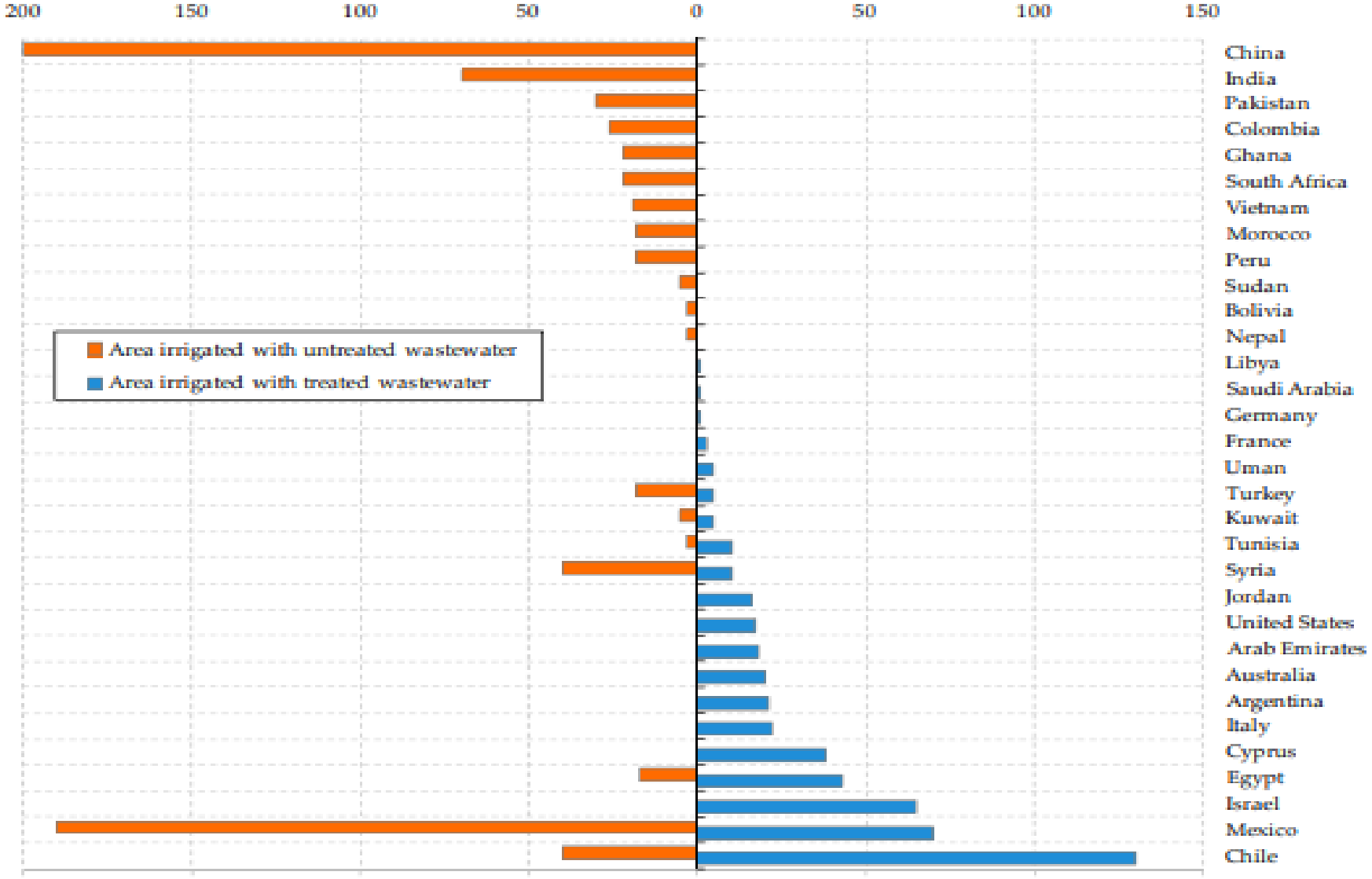
I. A tenth of the world's irrigated crops (about 20 million ha) are irrigated with wastewater (treated and untreated)

- More 2 million ha in China alone
- Unplanned and/or inadequate planning of direct and indirect use of untreated wastewater worldwide.

II. Key drivers for the expansion of wastewater irrigation

- Increasing water scarcity and stress
- Increasing urbanization, and growing urban wastewater flows in developing countries
- Lack of food security
- Increasing environmental pollution from improper wastewater disposal
- Recognition of the resource value of sewage

Background & Context: Reuse area in agriculture by country (thousand ha)



Basis of successful wastewater reuse programs:

I. Appropriate treatment scheme to meet water quality requirements and environmental regulations for the intended reuse.
II. Economic viability
III. Protection of public health and the Environment
IV. Gaining public acceptance.

Water Quality Considerations

I. **Physical water quality considerations**
   - Turbidity, color, etc.

II. **Chemical water quality considerations**
   - Chemical constituents including solids, metals, nitrogen, phosphorus, etc.

III. **Biological water quality considerations**
   - Pathogens (bacteria, helminthes, virus, etc.)

IV. **Micro-pollutants considerations**
   - Pharmaceuticals, hormonal products, personal care products, etc.

Benefits & Risks of Wastewater Use

Benefits of Wastewater Use

Wastewater (If managed properly) can provide beneficial effects for society, the economy and the environment; and enhancing food security as following:

I. Agricultural benefits (useful and valuable nutrients that are required by plants).
II. Water resources management benefits (an alternative water supplies), specially in a country like Egypt which consumes more than 80% of available water in irrigation
III. Environmental benefits & reduced pollution (such as algal blooms & eutrophication)

Potential Negative Effects of Reclaimed Water

Category	Example of constituents	Potential effects
Nutrients and trace elements	• Nitrogen • Phosphorus • Potassium • Calcium • Magnesium • Sulfate	• Toxic in excessive concentrations • Poor quality crop (due to excessive nitrogen during flowering/ fruiting phase) • Toxic to livestock in high concentrations in animal feed • Biofilms in pipelines • Algal growth in open stores or canals.
Suspended solids	• Particulates	• Clogging in sprinkler and drip irrigation emitters. • Subsequent Algae growth in storage caused by reclaimed water nutrients.
Salinity	• Total dissolved solids (Electrical conductivity)	• Plant stress and growth reduction • Salt accumulation in soil from irrigation water.
Sodicity	• Sodium (SAR)	Soil impermeability
Specific ion toxic elements	• Sodium, Chloride • Boron	Phytotoxicity (leaf damage, reduced productivity)

Risks of Wastewater Use

Wastewater contains a wide range of different constituents:

- Pathogens,
- Organic compounds,
- Synthetic chemicals,
- Nutrients,
- Heavy metals and;
- Emerging contaminants

Risks of Wastewater Use (continue..)

❑ Health Risks

I. **Biological contamination** of crops that eaten raw, such as salad crops, onions or radishes **(**e.g. intestinal helminthes infections or diarrheal diseases)

II. **Chemical contamination** with Heavy metals from industry or household detergents contained in the wastewater and micro-pollutants such as pharmaceutical residues.

III. **Polluted canals and streams** expose farmers, children and other inhabitants to pathogens, pollutants and bacteria.

IV. **Secondary Impacts** linked to high costs for health care and lost labour productivity and negatively affects the economic development and increase poverty.

Risks of Wastewater Use (continue…)

❑ Environmental Risks:

I. **Deterioration of the ecosystems**, however, could have significant secondary impacts, resulting in **a contamination of fish stocks, algae blooms**, the rise of marine dead zones and subsequent loss of livelihoods and food security

II. **Negative impacts** on irrigated crops, soils and groundwater are likely, which can affect not only human but also environmental health.

III. **Undesirable salts** or metals and metalloids in toxic concentrations, depending on their concentration and solubility

IV. **Eutrophication** is one of the major dominant global problems affecting the health and functioning of marine and freshwater ecosystems

Risks of Wastewater Use (continue…)

❑ Toxicity & Contamination Risk

I. **Metals and Metalloids** -Several of these metals and metalloids are of particular concern due to their adverse effects on agricultural productivity as well as environmental health, accumulates in plants, animals and humans due to their long biological half-life.

II. **Organic Contaminants**-Exposure of farmers and crops to organic contaminants is probably higher through pesticide application than organic contaminants in the irrigation water. Pesticide contamination is more likely to reach significant levels through direct on-site application

Guideline & Standards

- WHO
- FAO
- USEPA

WHO Guidelines – Pathogen Hazards with Sewage Reuse in Agriculture

WHO guidelines recognized different health risks for different groups exposed to sewage reuse and established specific measures to protect each group.

No	Hazard	Examples	Health Risk
1	**Bacteria**	Escherichia coli, Vibrio cholera, Salmonella	Bacteria die off more rapidly on crops than some other pathogens but still present a health risk
2	**Helminths Soil-Transmitted**	Ascaris, Ancylostoma, Taenia, Hymenolepis, Fasciola,	Major health risk because eggs can survive extended periods of time
3	**Protozoa**	Giardia, Entamoeba	Protozoa can survive in the environment long enough to pose health risk
4	**Virus**	Hepatitis, Rotavirus, Norovirus	Viruses can survive in the environment for long enough to pose health risks

WHO Guideline health-based targets for WWR in agriculture

- WHO has developed health-based targets to define level of health protection for a given exposure to hazards, based on a measure of the disease(Disability Adjusted Life Year-DALY)
  DALY=YLL (year Life Lost)+YLD (Year Life Disable) .
- WHO has developed a combination of health protection standards to achieve these health-based targets such as:
  - Crop restriction;
  - Sewage application techniques;
  - Measures to control exposure;
  - Treatment processes; and
  - Handling practices to reduce risk.
- WHO' approach specifically considers risks to the health to consumers of food crops with unrestricted irrigation and health risks to field workers with restricted & localized irrigation.

WHO health-protection measures and pathogen reduction

WHO health-protection measures for: Treatment, handling practices and irrigation methods, etc) & log unit reductions

No	Protection Measures	Pathogen Reduction Log Unit
1	Treatment	1 to 6
2	Localized Drip Irrigation (Low Growing Crops)	2
3	Localized Drip Irrigation (High Growing Crops)	4
4	Spray Irrigation	1
5	Pathogen Die Off	0.5 to 2 (per day)
6	Produce Washing	1
7	Produce Peeling	2
8	Produce Cooking	6 to 7
9	Produce Disinfecting	2

Drip Irrigation

Drip Irrigation:

In this method, water runs under pressure through to the soil surface that is adjacent to the roots of plants.

This system ensures the least contact of TWW with stems of plants and workers.

Sprinklers Irrigation

Sprinklers Irrigation:

Sprinklers irrigation that are characterized by low pressure and high discharge at an angle of no more than 11° with the horizontal plane.

WHO treatment processes and pathogen reduction

Treatment Level	Pathogen Removal (Log Unit)			
	Virus	Bacteria	Protozoa	Helminth Eggs
1.Primary treatment				
Primary Sedimentation	0-1	0-1	0-1	0-<1
Chemically Enhanced Primary treatment	1-2	1-2	1-2	1-3
Anaerobic Upflow Sludge Blanked Reactor	0-1	0.5-1.5	0-1	0.5-1
2.Secondary Treatment				
Activated Sludge/ Secondary Sedimentation	0-2	1-2	0-1	1-<2
Trickling Filters/ Secondary Sedimentation	0-2	1-2	0-1	1-2
Aerated Lagoon/ Settling Pond	1-2	1-2	0-1	1-3
3.Tertiary Treatment				
Coagulation/ Flocculation	1-3	0-1	1-3	2
Slow Rate Sand Filtration	1-3	0-3	0-3	1-3
Membranes	2.5->6	3.5>6	>6	>3
4..Disinfection				
Chlorination	1-3	2-6	0-1.5	
Ozonation	3-6	2-6	1-2	0-2
Ultraviolet Radiation	1->3	2->4	>3	0

WHO verification monitoring of wastewater treatment

WHO Provides verification monitoring levels of E. coli that correspond to a target pathogen reduction for different irrigation methods (Restricted & Unrestricted)

Type of Irrigation	Target Pathogen Reduction (Log Units)	Verification Monitoring Level (E. coli/100 ml)	Notes
1.Unrestricted	4	$\leq 10^3$	Root crops
	3	$\leq 10^4$	Leaf crops
	2	$\leq 10^5$	Drip irrigation of high growing crops
	4	$\leq 10^3$	Drip irrigation of low growing crops
	6-7	$\leq 10^1$ to $\leq 10^0$	Level depends on local regulatory agency
2.Restricted	4	$\leq 10^4$	Labor intensive agricultural practices
	3	$\leq 10^5$	Highly mechanical agricultural practices
	0.5	$\leq 10^6$	Pathogenic removal in septic tank

WHO maximum tolerable soil concentration based on human health protection (metals)

WHO –Health related permissible concentrations of metals in soil irrigated with sewage

No	Metal	Maximum Soil Concentration (mg/kg)	No	Metal	Maximum Soil Concentration (mg/kg)
1	Antimony	36	7	Mercury	7
2	Arsenic	8	8	Molybdenum	0.6
3	Barium	302	9	Nickel	107
4	Beryllium	0.2	10	Selenium	6
5	Fluorine	635	11	Silver	3
6	Lead	84	12	Vanadium	47

FAO-recommended water criteria for irrigation

FAO provided the suitability of sewage reuse with respect to salinity and trace elements for irrigation

Parameter	Degree of Restriction on Irrigation			
	Units	None	Slight to Moderate	Severe
Salinity				
EC *	dS/m	< 0.7	0.7-3.0	>3.0
TDS	mg/L	< 450	450-2,000	>2,000
Specific Ion Toxicity				
Sodium (Na)				
Surface Irrigation	SAR**	< 3	3-9	>9
Sprinkler irrigation	mg/l	< 3	>3	
Chloride (Cl)				
Surface irrigation	mg/l	< 4	4-10	>10
Sprinkler irrigation	mg/l	< 3	>3	
Boron (B)	mg/L	< 0.7	0.7-3.0	>3.0
Nitrate (NO_3-N)	mg/L	< 5	5-30	>30
Bicarbonate (HCO_3)	mg/L	< 1.5	1.5-8.5	>8.5
pH	-	6.5-8.4		

*** EC = electrical conductivity (deciSiemens/meter)**

**** SAR= Sodium Absorption Ratio**

FAO Guidelines for the “agricultural reuse of treated waters and treatment requirements

FAO classified the type of agricultural reuse based on the type of irrigated crop

No.	Type of Agricultural Reuse	Type of treatment	Quality Criterion
1	Agricultural reuse in crops that are consumed and not processed commercially.	Secondary Filtration-Disinfection	pH=6.5-8.4 BOD<10 mg/L <14 MPN E. coli/100 mL <1 Egg/L
2	Agricultural reuse in crops that are consumed and not processed commercially.	Secondary-Disinfection	pH=6.5-8.4 BOD<30mg/L SS<30 mg/L <200 MPN E. coli/100 mL
3	Agricultural reuse in crops that are not consumed.	Secondary-Disinfection	pH=6.5-8.4 BOD<30mg/L SS<30 mg/L <200 MPN E. coli/100 mL

FAO-recommended water criteria for irrigation (trace elements)

FAO recommended trace element criteria for sewage reuse for irrigation for irrigation

No	Trace Element	Maximum Concentration (mg/L)	No	Trace Element	Maximum Concentration (mg/L)
1	Aluminum	5.0	10	Iron	5.0
2	Arsenic	0.1	11	Lead	5.0
3	Beryllium	0.1	12	Lithium	2.5
4	Boron	0.75	13	Manganese	0.2
5	Cadmium	0.0	14	Molybdenum	0.01
6	Chromium	0.1	15	Nickel	0.2
7	Cobalt	0.1	16	Selenium	0.02
8	Copper	0.2	17	Vanadium	0.1
9	Fluoride	1.0	18	Zinc	2.0

USEPA guidelines for sewage reuse for irrigation

Reuse Category	Level of treatment	Reclaimed Water Quality
Agriculture		
Food Crops	**Secondary* Filtration** Disinfection***	pH=6.0-9.0
		BOD≤10 mg/L
		Turbidity≤ 2 NTU
		Fecal coliform= No detect
		Cl_2 residual= 1 mg/L
Agriculture		
Non-food Crops	**Secondary Disinfection**	pH=6.0-9.0
		BOD≤30 mg/L
		TSS≤30 mg/L
		Fecal coliform≤ 200 CFU/ 100 ml
		Cl_2 residual= 1 mg/L

* Secondary treatment includes activated sludge processes, trickling filters, rotating biological contractors

** Filtration includes filter media sand membrane processes

*** Disinfection includes chlorination ozonation, other chemical disinfectants, UV, membrane processes

Summary of Health Risks Associated with the Use of Wastewater for Irrigation (WHO & FAO Guidelines 2006)

Health risks			
Group Exposed	**Helminth infections**	**Bacterial/Virus infections**	**Protozoal infections**
Consumers	Significant risk of helminthes for both adults and children with untreated wastewater	Cholera and typhoid outbreaks reported from use of untreated wastewater; (increase in non-specific diarrhea when water exceeds 10^4 coliforms/ 100ml)	Evidence of parasitic protozoa found on wastewater- irrigated vegetable surfaces, but no direct evidence of disease transmission.
Farm workers and their families	Significant risk of Helminths for both adults and children in contact with untreated wastewater; increased risk of hookworm infection for workers who do not wear shoes; even when wastewater is treated to <1 Helminths egg per liter	Increased risk of diarrheal disease in young children with wastewater contact if water quality exceeds 10^4 coliforms/100 ml)	Risk of Giardia intestinal is infection reported to be insignificant for contact with both untreated and treated wastewater;
Nearby communities	Transmission of Helminth infections not studied for sprinkler irrigation, but same as above for flood or furrow irrigation with heavy contact	Sprinkler irrigation with poor water quality (10^6 -10^8 total coliforms/100ml) and high aerosol exposure associated with increased rates of infection.	No data on transmission of protozoan infections during sprinkler irrigation with wastewater.

Major Findings!

I. Previous WHO (1989) guidelines for sewage reuse were mainly based on conformance to specific water-quality thresholds.

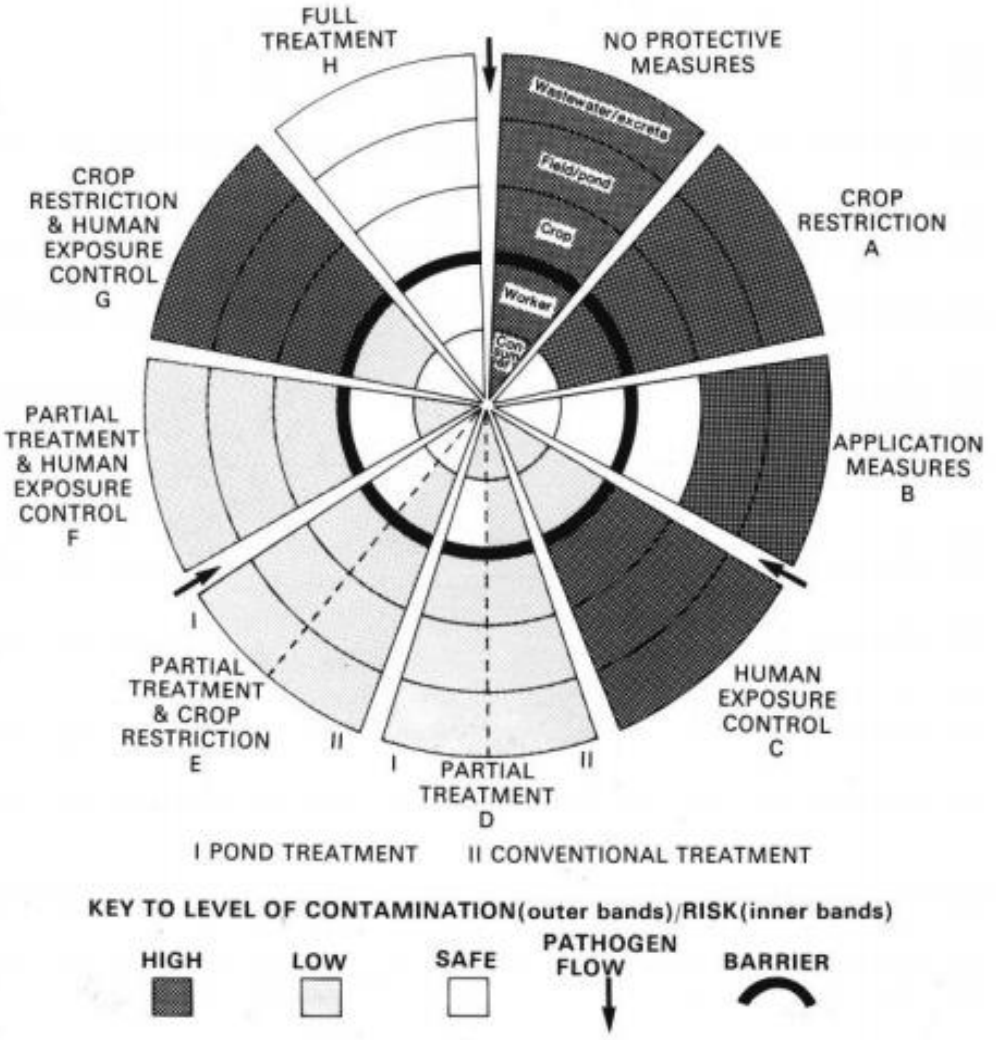
II. WHO recent approach recognizes that conventional WWT may not always be feasible and offers alternative measures that can reduce the risk of sewage reuse.

III. Current WHO guidelines, released in 2006, applied a comprehensive risk assessment ,management framework & health protection measures through **Multiple-Barrier Approach (MBA)**

Health Protection Measures — "Multi-Barrier Approach"

WHO Guidelines 1989

- In WHO Guidelines (1989), conventional wastewater treatment was regarded as almost the exclusive option for mitigating the risks of wastewater use.
- It became increasingly clear that WHO, 1989 needed more input on other forms of health protection measures when use raw or partially treated wastewater in agriculture either direct or indirect



Full treatment: ≤1 Helminths egg per liter and ≤1000 fecal coliforms per 100 ml.

Crop restriction : Not irrigating salad crops and vegetables that may be eaten uncooked,

Application measures :Use of drip irrigation, and

Human exposure control :Protective clothing, gloves, footwear, and hand washing facilities, to fieldworkers

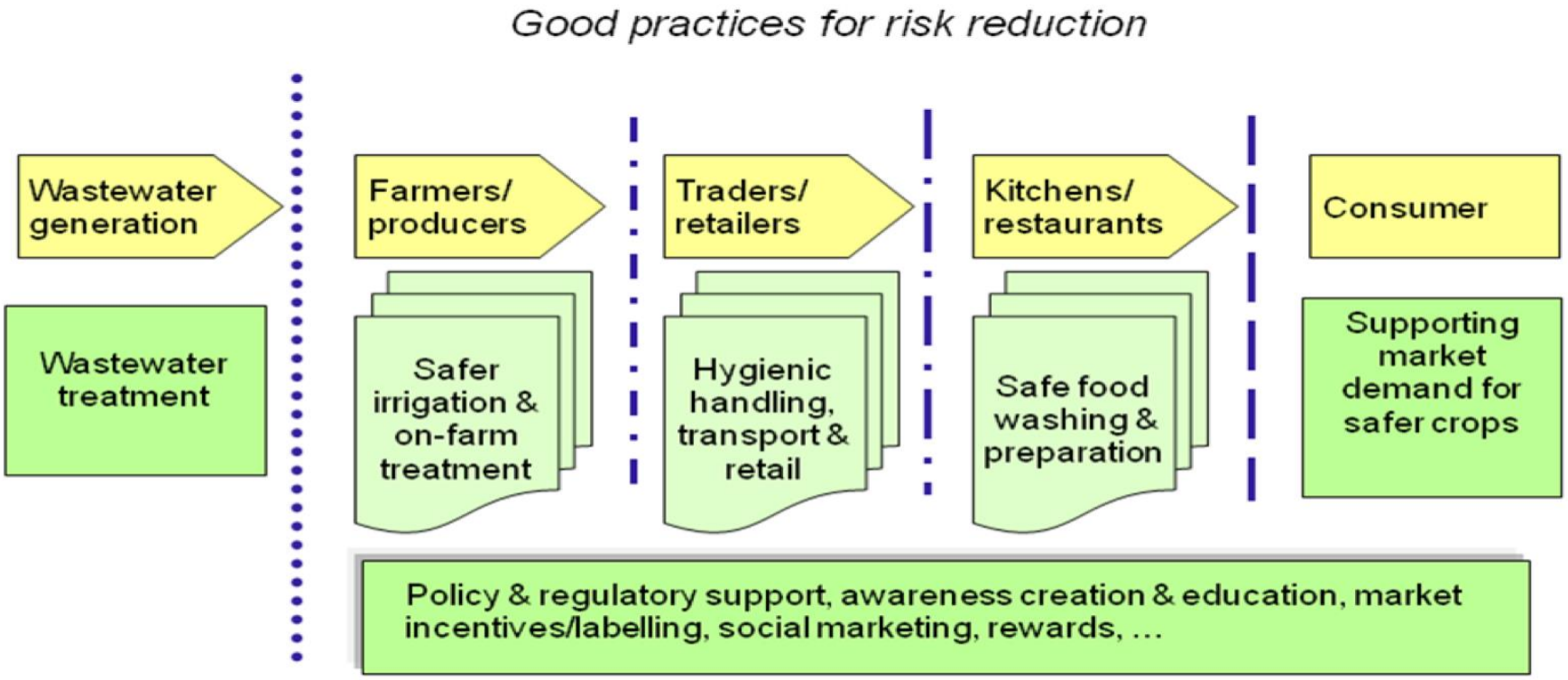
Multiple-barrier approach (WHO 2006)

- WHO Guidelines (2006) provided a protection against contaminants at each step along the water to food pathway, beginning at the wastewater source, continuing at the treatment facility and extending through the farm and market chain to the kitchen where the food is prepared and eventually served. This approach is commonly referred to as the **"Multiple-Barrier Approach**"

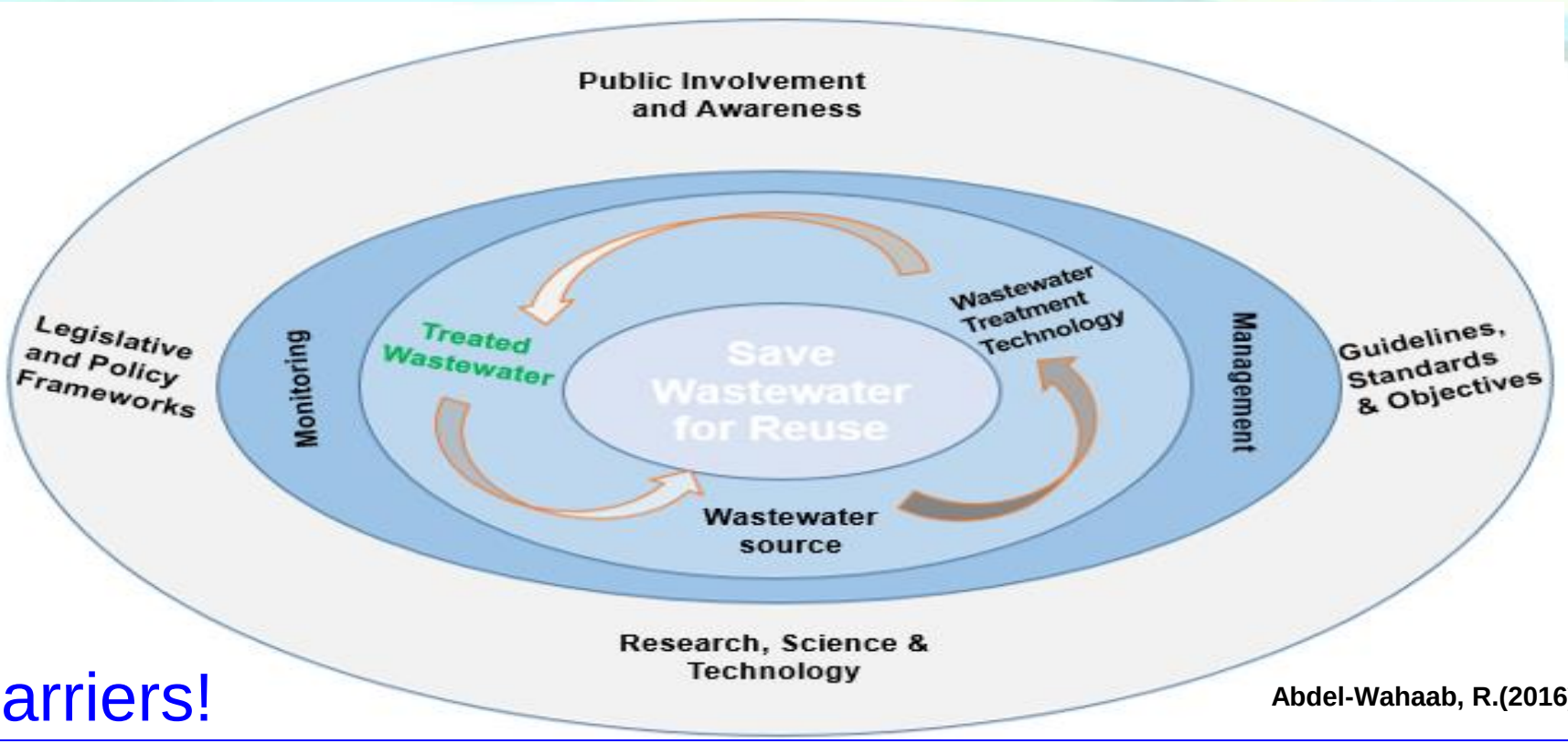
- **The Multi-Barrier Approach is**:
  "an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of in order to reduce risks to public health"

Multiple-Barrier Approach

- Multiple-barrier approach in the wastewater food chain where treatment alone is an insufficient pathogen barrier
- It proposed a series of barriers along the reuse chain, instead of focusing only on treatment infrastructure for the improvement of wastewater quality to be reused.



The Multi-Barrier Approach to Save Wastewater Reuse



Abdel-Wahaab, R.(2016)

Barriers!

1. **Legislative & Policy frameworks** : Outline who is responsible and their specific responsibilities.
2. **Public Involvement & Awareness :** Informing the public about health risks and providing educational materials on issues .
3. **Guidelines & Standards:** Would add a new dimension to source protection efforts and would complement the multi-barrier approach.
4. **Research, Science & Technology:** Innovative methods & technology will help the ultimate health outcomes and benefits of a multi-barrier approach.
5. **Management: P**lans dealing with potential sources of contamination of great benefits for MBA application
6. **Monitoring:** Ensure **c**ompliance with laws & regulations
7. **Wastewater Source**: Assess the quality of waterwater & sources contaminations (Industrial WW)**.**

Health Protection Measures

Health protection measures should be developed to ensure providing protection to the various exposed groups – consumers, workers and their families and nearby communities as follows:

I. Wastewater treatment
II. Crop restriction
III. Wastewater application techniques that minimize crop contamination (e.g. drip irrigation)
IV. Withholding periods to allow pathogen die-off after the last wastewater application
V. Hygienic practices at food markets and during food preparation
VI. Health and hygiene promotion
VII. Produce washing, disinfection and cooking
VIII. Medication (e.g anti-helminthic drugs) and immunization
IX. Use of personal protective equipments
X. Access to safe drinking-water and sanitation facilities at farms
Disease vector and intermediate host control

Emerging Contaminants

- What are they?
- Major Groups
- Sources & Passways

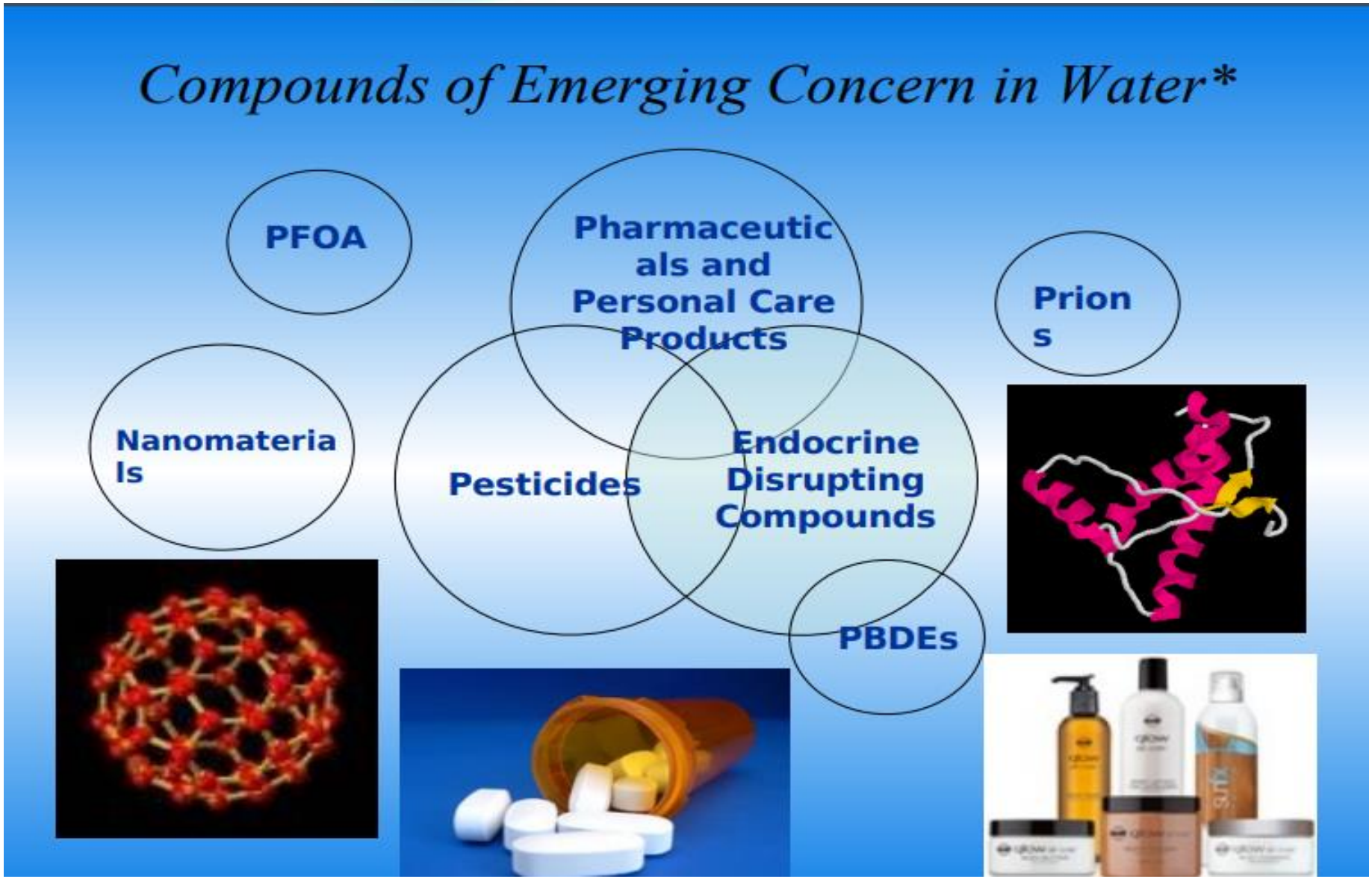
Emerging Contaminants (What Are They?)

Emerging contaminants are chemicals that had not previously been detected in the water supplies and for which the risk to human health is not yet fully understood.

Recently, the prime examples of emerging contaminants that discovered in the water supply are:

- Pharmaceuticals,
- Personal care products and
- Endocrine disrupting compounds (substances that may interfere with the function of hormones in the body)

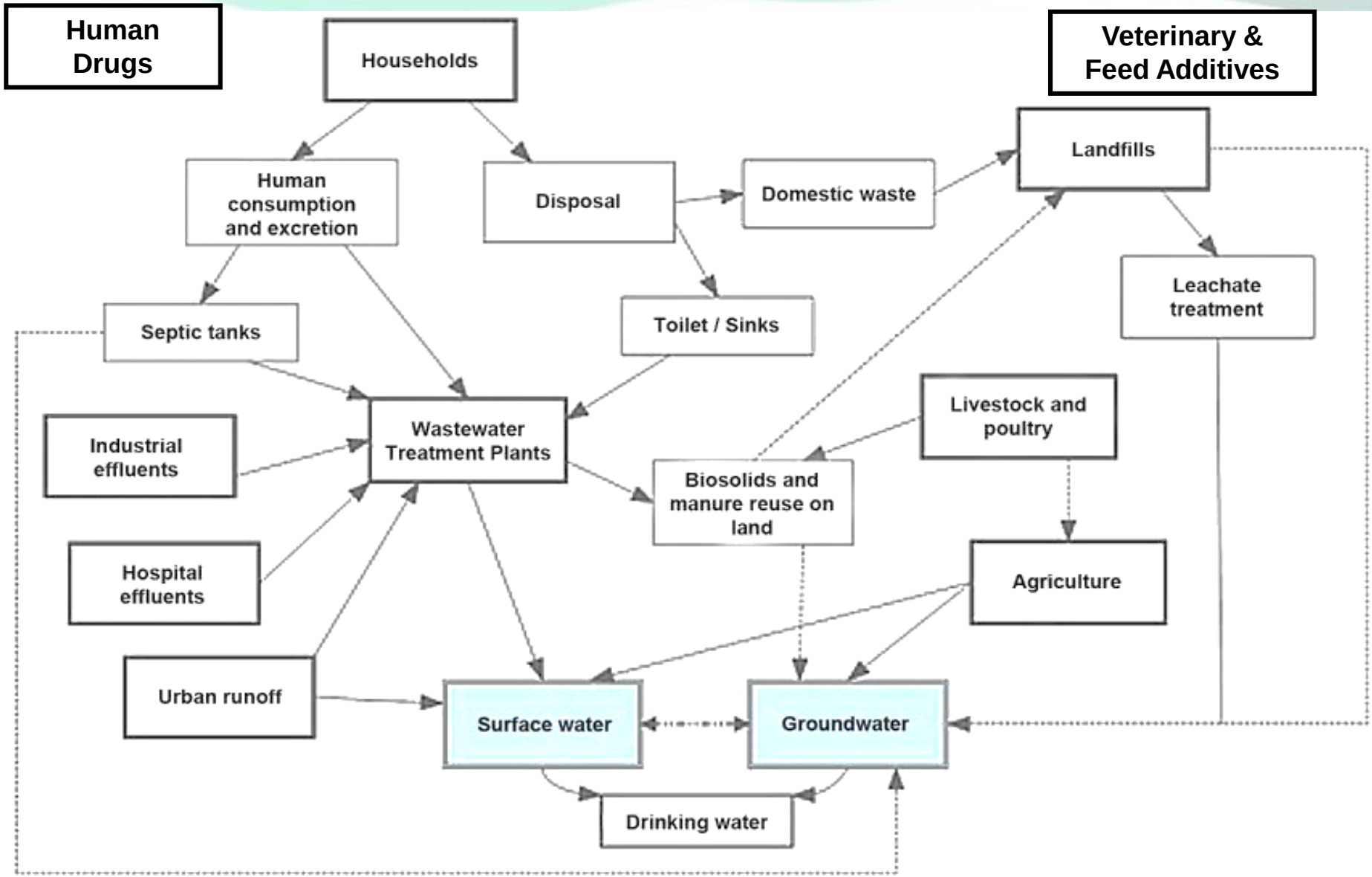
Emerging Contaminants (List of major groups?)



Emerging Contaminants (List of major groups?)

Emerging Contaminant Groups	Examples
Pharmaceuticals	
Human antibiotics and veterinary	Trimethoprim, erytromycine, amoxicillin, lincomycin, sulfamethaxozole, chloramphenicol
Anti-inflammatory drugs	Ibuprofene, diclofenac, paracetamol, codein, acetaminophen, acetylsalicilyc acid, fenoprofen
Psychiatric drugs	Diazepam, carbamazepine, primidone, salbutamol
Lipid regulators	Bezafibrate, clofibric acid, fenofibric acid, etofibrate, gemfibrozil
X-ray contrasts	Iopromide, iopamidol, diatrizoate
Personal Care Products (PCPs)	
Fragrances	Nitro, polycyclic and macrocyclic musks, phthalates
Sun-screen agents	Benzophenone, methylbenzylidene campho
Insect repellents	N,N-diethyltoluamide
Endocrine Disrupting Chemicals (EDCs)	Octylphenols, nonylphenols, Di(2-ethylhexyl)phthalate (DEHP)
Hormones and Steroids	
Perfluoronated compounds	Perfluorotoctane sulfonates (PFOs), perfluoroctanoic acid (PFOA)
Flame retardants	Polybrominated diphenyl ethers (PBDEs):
Industrial additives and agents	Chelating agents (EDTA), aromatic sulfonates
Antiseptics	Triclosan, chlorophene

Emerging Contaminants (Sources & Passways)



Emerging Contaminants (Available Standards in Different Countries)

Substance	Drinking Water health/aesthetic	Fresh	Marine	Recreation	Agriculture	Notes
Benzo[a]pyrene	**0.01 µg/L**	***0.2 µg/L**	***0.2 µg/L**	**0.01 µg/L**	-	
MTBE	0.02 mg/L for MTBE based on its odour threshold (Canada Health)	3.4 mg/L (BC, Canada)	0.44 mg/L (BC, Canada)	0.02 mg/L (BC, Canada)	11 mg/L for livestock watering (BC, Canada)	
	0.02–0.04 mg/L for organoleptic responses (US)	51 mg/L long term, 151 mg/L short term (US)	18 mg/L long-term, 53 mg/L short-term (US)	In absence of specific criteria, drinking water guidelines are used (US)	In absence of specific criteria, drinking water guidelines are used (US)	
PFOS	0.3 µg/L (US/Minnesota)	0.65 ng/L (US)	-	As above	As above	Important to base criteria on fish consumed (pathway)
		0. 65 ng/L (Netherlands)	0.00053 µg/L (Netherlands)			0.53 µg/L for surface water intended for drinking (Netherlands)
PFOA	0.04 µg/L (USA/New Jersey) 0.02 µg/L (USA/Nth Carolina)	-	-	As above	As above	
	10 µg/L (UK)					
PBDE						
triBDE	0.0005 µg/L (EC)	46 ng/L (BC, Canada)		As above	As above	
tetraBDE	0.0005 µg/L (EC)	24 ng/L (BC, Canada)		As above	As above	
pentaBDE	0.0005 µg/L (EC)	0.2 ng/L (BC, Canada)		As above	As above	
hexaBDE	0.0005 µg/L (EC)	120 ng/L (BC, Canada)		As above	As above	
octBDE	0.0005 µg/L (EC)	17 ng/L (BC, Canada)		As above	As above	
nonaBDE	0.0005 µg/L (EC)	-		As above	As above	
decDBE	0.0005 µg/L (EC)	-		As above	As above	
Weathered hydrocarbons						
Phenol	6mg/L for up to 10 days (US) 5mg/L (Japan), 0.5mg/L (EC)	**320**	**400**	**(Phenolics: 2)**	As above	
Others	-	-	-	As above	As above	

Pilot Study-Fate of pathogens in crops irrigated with TWW (South Cairo)

Pilot Study – Fate of pathogens in crops irrigated with TWW (South Cairo)

Helwan WWTP	pH	COD mg /l	BOD mg /l	Total Bact. Count / ml		MPN- index/100 ml				
				At 37°C	At 22°C	TC	FC	E. coli	F.S	Salmo-nella
Raw Waste-water	7.4	271	165	$5x10^7$	$2x10^6$	$1.1x10^5$	$1.1x10^5$	$2.1x10^4$	$3x10^4$	$1.2x10^2$
Treated Effluent	7.3	143	111	$2x10^5$	$5x10^4$	$2.1x10^3$	$4.5x10^2$	$1.6x10^2$	$2.8x10^2$	80
Agricultural Drain	7.6	88	38	$6x10^6$	$8.8x10^5$	$2.4x10^6$	$1.4x10^5$	$1.1x10^4$	$1.1x10^5$	$1.4x10^2$

Source: R.Wahaab (2017)

Pilot Study – Fate of pathogens in crops irrigated with TWW (South Cairo)

The unplanned use of partially treated wastewater in developing countries gives rise to increasing risks to people, plants, and the environment!

No	Washing Water Sample	Total Bact. Count CFU/ 1ml		MPN= - index/100 ml				
		At 37°C	At 22°C	Total Coliform	F. Coliform	E. coli	F. Strept.	Salmonella
1	Mulberry*	$3.2x10^3$	$5.4x10^3$	$2.1x10^3$	$2.1x10^2$	90	$2.8x10^2$	$1.1x10^2$
2	Spinach**	$2x10^3$	$3.2x10^3$	70	40	N.D	30	20
3	Green ** Onion	$4x10^2$	$3.5x10^3$	N.D	N.D	N.D	N.D	N.D
4	Green ** Beans	$1.1x10^4$	$6x10^4$	$2.1x10^2$	40	N.D	40	30

Source: R.Wahaab (2017)

* Eaten raw

** Eaten raw & cooked

Wastewater Reuse Project in Egypt –Success Case!

Quantity of Produced Treated Sewage Water	30,000 M 3 daily
Forest Area In Feddans	1650 F
Tree Species Planted	Castor, Khaya, Jatropha, Gogopa
Irrigation System Used	Drip Irrigation /flooding

Aswan

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For further information

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Thank you for your attention.

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