WASTEWATER REUSE

FOR

IRRIGATION

PAKISTAN WATER OPERATORS NETWORK

(March-2022)

PREFACE

On behalf of All water utilities in Pakistan PWON is thankful to JICA for providing Support for ***Management of Water & Sanitation Services in Punjab against Covid-19*** through which lectures / webinars were arranged January 2022, to end March 2022, for ***Better Management of Water & Sanitation Services during Outbreak*** as well *as* ***Awareness & Preventive Measures against Covid-19*** *and* ***Preparation of in house Disinfection by Water & Sanitation Utilities.***

On demand of PWON members, lectures for capacity building of utilities in Pakistan about various important technical topics were also added along with above lectures / webinars / seminars. All these events were well participated and appreciated by all utilities

On demand of member utilities PWON has published these lectures for capacity building and references for improvement of their day to day working for the benefit of their consumers at large. This book on the topic of **WASTEWATER REUSE FOR IRRIGATION** is published by PWON for the benefit of all its members.

PWON is thankful to Capt. (R) Muhammad Hafeez for Preparing this valuable document.

Syed Zahid Aziz
CHAIRMAN
PWON, Pakistan

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1. TYPICAL WASTEWATER CONSTITUENTS

Residual constituents	**Effects**
(A) Inorganic and organic colloidal and suspended solids:	
• Suspended solids	May cause sludge deposit or effect clarity of receiving body. Can impact disinfection by shielding organisms
• Colloidal solids	May effect effluent turbidity
• Organic matter(particulate)	May shield bacteria during disinfection. May deplete oxygen resources
(B) Dissolved organic matter	
• Total organic carbon	May deplete oxygen resources
• Refractory organics	Toxic to humans; carcinogenic
• Volatile organic compounds	Toxic to humans; carcinogenic
• Pharmaceutical compounds	Impact aquatic species
C Dissolved inorganic matter:	
• Ammonia	Increase chlorine demand. May deplete oxygen resources. Toxic to fish
• Nitrate	Stimulates algal and aquatic growth. May be harmful to infants.
• Phosphorus	Stimulates algal and aquatic growth. Interfere with coagulation.
• Calcium & magnesium	Increase hardness and TDS
• Chloride	Salty taste
• TDS	Interfere with agricultural and industrial process.
(D) Biological	
• Bacteria, protozoan cysts,Viruses	May cause disease

2. MAJOR TYPES OF REUSE OF TREATED WASTEWATER

Two major types of reuse have been developed and practiced throughout the world:

(1) potable uses

- ❖ direct, use of reclaimed water to augment drinking water supply following high levels of treatment
- ❖ indirect after passing through the natural environment

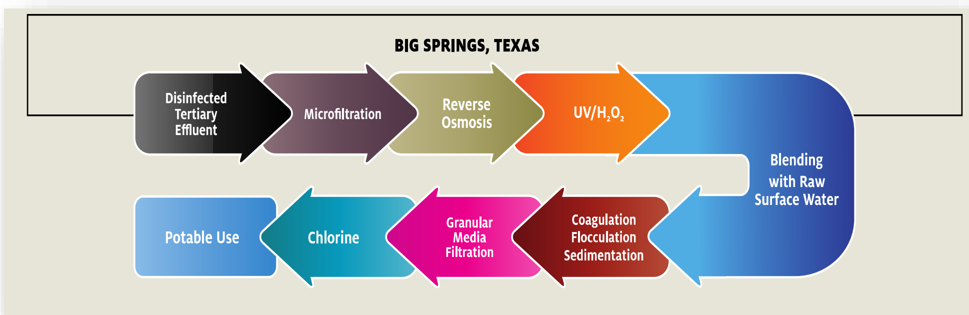
(2) non-potable uses

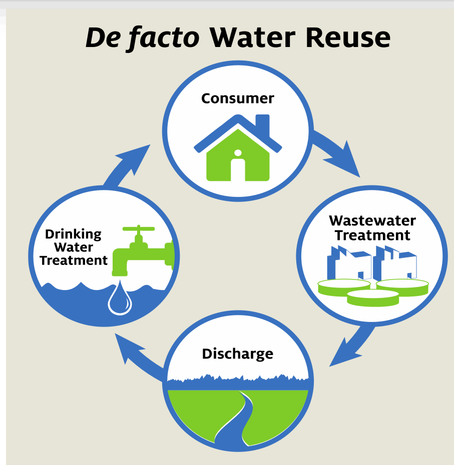
- ❖ irrigated agriculture
    - ❖ use for irrigating parks, public places of forestry (fastest reuse application in Europe: Irrigation of golf courses)
    - ❖ use for aquaculture
    - ❖ aquifer recharge (indirect reuse)
    - ❖ or uses in industry and urban settlements

3. HISTORIC DEVELOPMENT OF WATER REUSE

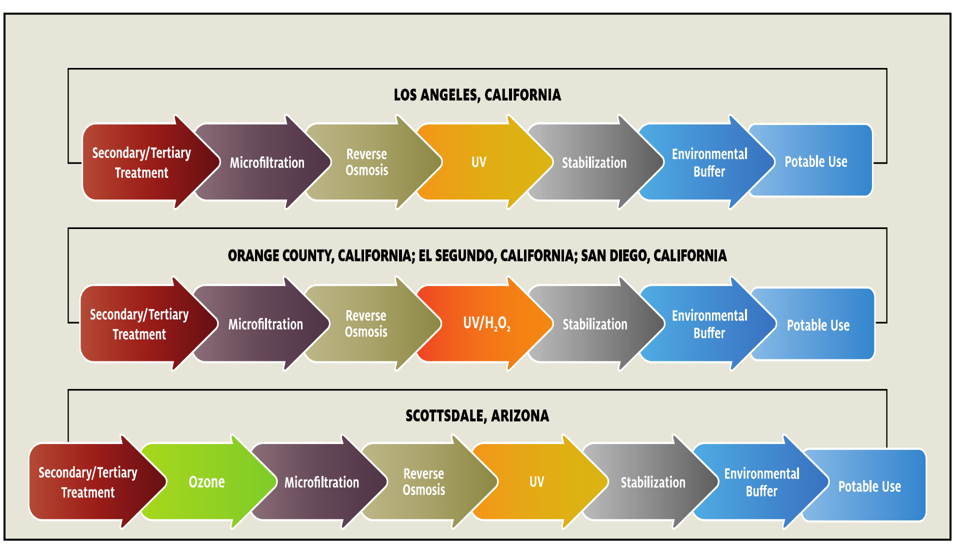
year	Location	Reuse application
1929	City of Panama	Irrigation of Lawn and Gardens
1960	City of Colorodo springs	Golf cources
1962	Los Angles County	Ground water recharge
1987	Monterey,CA	Irrigation of food crops
1984	Tokyo	Providing reclaimed water to 19 high-rise buildings in Shinjuku
2010?	Singapore	Portable water

4. RELEASE TREATED WASTEWATER INTO LARGE BODIES OF WATER SUCH AS RIVERS OR RESERVOIRS





4.1 Indirect potable reuse



4.2 How Namibia turns sewage into drinking water

9 MGD Plant.

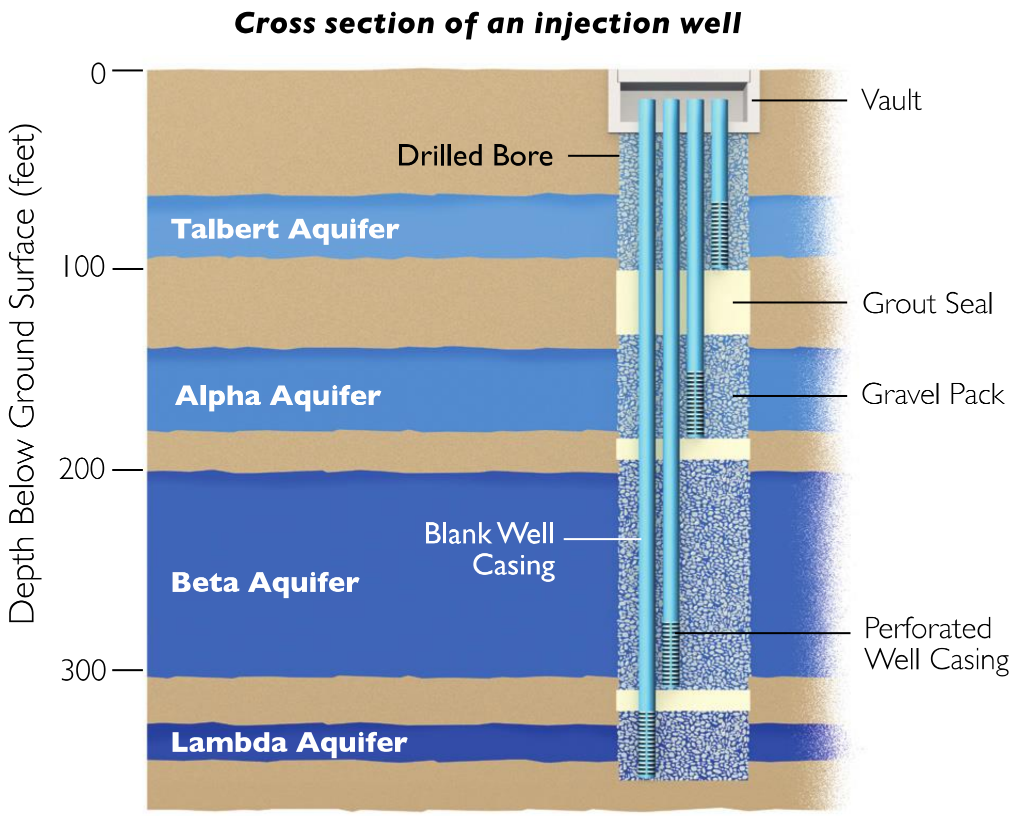
Treatment steps, include:

1. Conventional treatment,
2. Powdered activated carbon,
3. Pre-ozonation
4. Coagulation/Flocculation,
5. Dissolved air floation (DAF),
6.Rapid sand filtration
7. Ozonation,
8. biological and granular activated carbon filtration
9. ultrafiltration 10.Chlorination

4.3 Ground water recharging by treated wastewater

Recharge basins: 31 acres, 25 acres and 13.2 acres

4.4 Ground water injection. Orange County

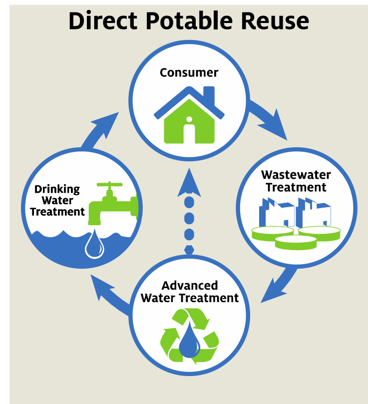


4.5 Orange county San Diego USA

- After wastewater treatment with microfilter, RO and advanced oxidation:
- Approximately 35 million gallons *(132,500 cubic meters)* per day of GWRS water are pumped into injection wells to create a seawater intrusion barrier.
- Another 65 million gallons *(246,000 cubic meters)* are pumped daily to Orange County Water District's percolation basins in Anaheim where the GWRS water naturally filters through sand and gravel to the deep aquifers of the groundwater basin to increase the local drinking water supply.

4.6 Advanced purified bottled water sourced from wastewater Orange County San Diego USA

- Forty years of water reuse technology and experience is now available in a bottle!
- In March of 2017, the Orange County Water District (OCWD) and Orange County Sanitation District (OCSD) took 13,000 bottles of GWRS purified water on the road to various events to share information about water reuse
- and to provide a taste to audiences who would otherwise not have the opportunity to try it.



4.7 From toilet to tap: NEWater Singapore

- ❖ The most difficult challenge for Singapore to overcome was persuading people to drink the urine.
- ❖ To combat this, a dedicated communications team conducted a massive public education campaign which included a TV documentary.

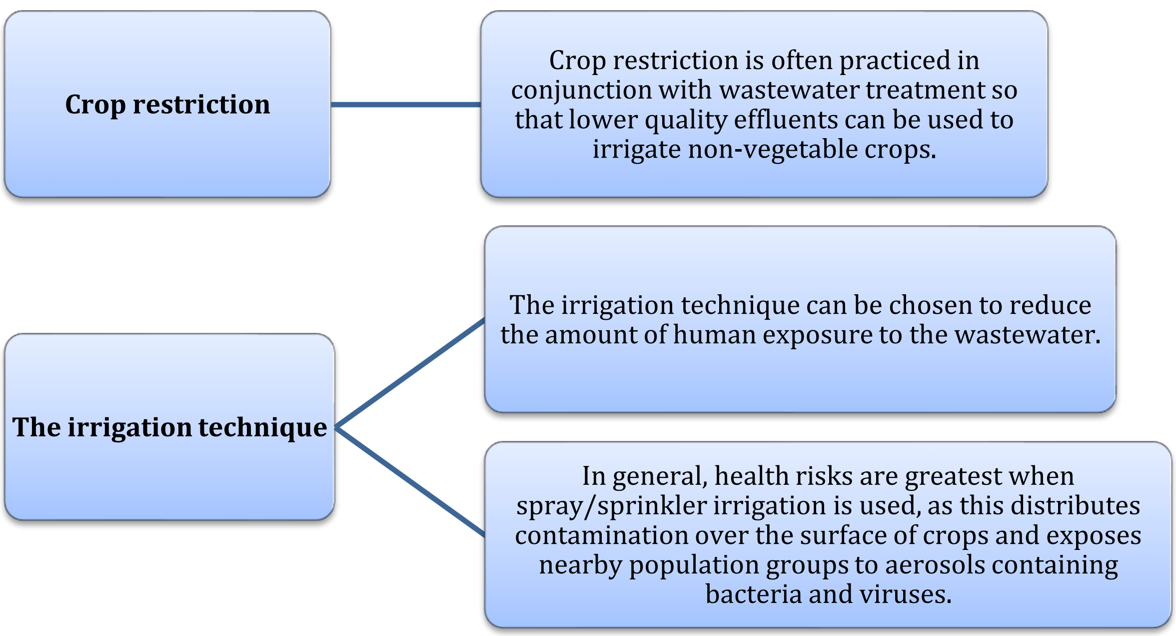
- ❖ They also released the cleaned-up wastewater into reservoirs where it got re-treated along with regular tap water.
- ❖ Psychologically, this extra step was vital in helping the people of Singapore accept NEWater as drinkable water.

5. TREATED WASTE WATER USE FOR AGRICULTURE

5.1 The re-use of untreated wastewaters for agriculture

- The World Health Organization has produced guidelines for the microbiological quality of treated wastewaters used in agriculture and aquaculture
- The re-use of untreated wastewaters in agriculture or aquaculture is known to cause an excess transmission of certain excreta-related diseases.
- They must be removed to a level which does not cause excess disease in the people working in the wastewater-irrigated fields or wastewater-fertilized aquaculture ponds.

5.2 Restriction according to origin and use of wastewater



5.3 Use of untreated wastewater for irrigation

- The farmers in the peri-urban areas in many countries are traditionally using untreated municipal wastewater for agriculture.
- its use is increasingly becoming popular due to the reasons that Wastewater may supply organic matter and mineral nutrients to soil that are beneficial to crop production, and reduce the cost of fertilizer application.
- In arid regions, wastewater is especially valued as an additional resource.
- However, urban wastewater may also contain hazardous substances including heavy metals and pathogenic microorganisms.
- These substances eventually harm the environment, human health, soil, groundwater and crops.
- Many countries have developed guidelines and quality criteria of wastewater reuse for agricultural irrigation purposes.
- In Pakistan no specific standards exist for wastewater reuse.

5.4 Various Guidelines and quality criteria for agricultural reuse of wastewater

- Manual of wastewater reuse (USEPA, 2012).
- The WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater.
- Guidelines for treated wastewater use for irrigation projects (ISO2015)
- The European Commission's Science for Policy report by the Joint Research Centre (JRC),

6. TYPES OF CROPS

- Agricultural irrigation is defined by JRC report as irrigation of the following types of crops:
- Food crops consumed raw: crops, which are intended for human consumption to be eaten raw or unprocessed.
- Processed food crops: crops, which are intended for human consumption not to be eaten raw but after a treatment process (i.e. cooked, industrially processed).
- Non-food crops: crops, which are not intended for human consumption (e.g. pastures, forage, fiber, ornamental, seed, energy and turf crops).
- These definitions are based on the categories of use described in water reuse guidelines (WHO,; USEPA, 2012; JRC, 2014).

6.1 Health and environmental risks considered for agricultural irrigation

- Health risks established based on the exposure scenarios recommended by WHO guidelines are the following:
- Ingestion of irrigated crops by consumers.
- Ingestion of droplets (produced by sprinkler irrigation) by workers, bystanders and residents in nearby communities.
- Inhalation of aerosols (produced by sprinkler irrigation) by workers, bystanders and residents in nearby communities.
- Dermal exposure by workers, bystanders and residents in nearby communities.
- Ingestion of soil particles by workers, bystanders and residents in nearby communities.
- Ingestion of pastures and fodder by milk- or meat-producing animals (human and animal health).
- Contamination of drinking water sources.

6.2 Salinity in developing countries (WHO)

- In developing countries, salinity is usually the dividing line between water suited or unsuited for irrigation uses.
- Heavy metal concentrations are as a rule still relatively low in developing countries and are not yet responsible for any major problems.
- High salt concentrations in irrigation water hamper the water intake of crops and lead to yield losses for many crops. In addition, high sodium contents in loamy soils lower their permeability for water, which results in lower soil aeration.

6.3 Unrestricted Irrigation WHO

- Use of high quality effluents, instead of freshwater, to irrigate any crop on any type of soil, which means without limitations.
- Contact and even accidental drinking do not pose health risks.
- Crops without any restriction include also vegetables eaten raw.

6.4 Restricted Irrigation WHO

- use of low quality effluents in limited areas and for specific crops only
- Restrictions are imposed based on the type of soil, irrigation method, crop harvesting technique, and fertilizer application rate
- to small amounts of wastewater, used in specific locations, where areas and crops are well-defined and unlikely to change
- Imposed crop limitation must be enforced and controlled.

- Farmers must be trained to handle the low-quality effluent

6.5 Microbiological parameters for monitoring

- Bacteria: *Escherichia coli* (*E. coli*) the most suitable indicator of fecal contamination.
- Biochemical Oxygen Demand (BOD5): BOD5 appears in the Australian and USEPA guidelines for agricultural irrigation, as well as in other guidelines ISO 16075, 2015). Some states include BOD5 in their water reuse legislations for agricultural irrigation (Cyprus, Greece and Italy).
- Total suspended solids (TSS): TSS is included in the USEPA guidelines for monitoring of processed food crops and non-food crops irrigation (USEPA, 2012), The Australian guidelines and The ISO guidelines
- **Turbidity**: Turbidity appears in the USEPA guidelines for food crops eaten raw and aquifer recharge, similarly to the Australian guidelines and ISO guidelines.

6.6 WHO Guidelines

- The Guidelines for the Safe Use of Wastewater, Excreta and Greywater:
- Volume I, Policy and regulatory aspects; Volume II, Wastewater use in agriculture;
- Volume III, Wastewater and excreta use in aquaculture;
- Volume IV, Excreta and grey water use in agriculture.
- The WHO recommends the implementation of a risk management plan including a risk assessment for water reuse systems. For this purpose, the WHO has launched a Sanitation Safety Planning (SSP) manual as guidance on implementation of the WHO guidelines for water reuse (WHO, 2015).

6.7 WHO microbiological quality guidelines for wastewater use in agriculture

Category	Reuse conditions	Exposed group	Intestinal nematodes (arithmetic mean no of eggs per litrer)	Faecal coliforms (geometric mean no per 100 ML)
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parksd	Workers, consumers, public	≤ 1	≤ 1000
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and treese	Workers	≤ 1	No standard recommended
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable

6.8 Wastewater reuse in the Eastern Mediterranean Region. WHO Regional Centre for Environmental Health Activities, CEHA, 2006).

- This compendium provides an overview of the quality standards for the reuse of treated wastewater in countries of the Eastern Mediterranean Region.
- Information was collected through surveys and from the Centre for Environmental Health Activities (CEHA), who contacted countries requesting that ministries of health provide pertinent standards and regulations for wastewater reuse quality in their countries.
- Guidelines are available for Jordan, Kuwait, Saudi Arabia and Tunisia.
- No specific standards are promulgated for wastewater reuse in Egypt, Iraq, Lebanon, **Pakistan** or Palestine.

6.9 Types of Irrigation

Surface Irrigation

Drip Irrigation

Sprinkle

7. WHO CEHA: RECOMMENDED GUIDELINES FOR TREATED WASTEWATER IN AGRICULTURE

Category	Reuse conditions	Exposed group	Irrigation technique	Intestinal nematodes (arithmetic mean no of eggs per liter)	Thermo tolerant coliforms (geometric mean no. per 100 mL)	Wastewater treatment expected to achieve required microbiological quality
A	Unrestricted irrigation For vegetable and salad crops eaten uncooked, sports fields, public parks	Workers, consumers, public	Any	$<$ detection	$\leq 10^3$	WSP with 21 days retention time or secondary treatment followed by equivalent storage or slow sand filtration or equivalent
B	Restricted irrigation Cereal crops, industrial crops, fodder crops, pasture and trees	Workers, nearby communities	Spray or sprinkler	$<$ detection	$\leq 10^5$	As for category A
		Workers, nearby communities	Flood/surface irrigation	$<$ detection	$\leq 10^3$	As for category A
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

7.1 Crop category & minimum reclaimed water quality class at EU level

Crop category	Minimum reclaimed water quality class	Irrigation method
All food crops, including root crops consumed raw and food crops where the edible portion is in direct contact with reclaimed water	Class A	All irrigation methods allowed
Food crops consumed raw where the edible portion is produced above ground and is not in direct contact with reclaimed water	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Processed food crops	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Non-food crops including crops to feed milk- or meat-producing animals	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Industrial, energy, and seeded crops	Class D	All irrigation methods allowed

7.2 Minimum reclaimed water quality criteria at EU level

Reclaimed water quality class	Indicative technology target	Quality Criteria			
		E. coli (cfu/100m l)	BOD5 (Mg/l)	TSS (Mg/l)	Turbidity (NTU)
Class A	Secondary treatment, filtration, disinfection (advance treatment)	≤10	≤10	≤10	≤5
Class B	Secondary treatment and disinfection	≤100	≤25	≤35	-
Class C	Secondary treatment and disinfection	≤1,000	≤25	≤35	-
Class D	Secondary treatment and disinfection	≤10,000	≤25	≤35	-

7.3 USEPA Recommended heavy metals for irrigation

Table 3-5 Recommended water quality criteria for irrigation

Constituent	Maximum Concentrations for Irrigation (mg/L)	Remarks
Aluminum	5.0	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans
Boron	0.75	Essential to plant growth; sufficient quantities in reclaimed water to correct soil deficiencies. Optimum yields obtained at few-tenths mg/L; toxic to sensitive plants (e.g., citrus) at 1 mg/L. Most grasses are tolerant at 2.0 - 10 mg/L
Cadmium	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L; conservative limits are recommended
Chromium	0.1	Not generally recognized as an essential element; due to lack of toxicity data, conservative limits are recommended
Cobalt	0.05	Toxic to tomatoes at 0.1 mg/L; tends to be inactivated by neutral and alkaline soils
Copper	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/L
Fluoride	1.0	Inactivated by neutral and alkaline soils
Iron	5.0	Not toxic in aerated soils, but can contribute to soil acidification and loss of phosphorus and molybdenum
Lead	5.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	Tolerated by most crops up to 5 mg/L; mobile in soil. Toxic to citrus at low doses—recommended limit is 0.075 mg/L
Manganese	0.2	Toxic to a number of crops at few-tenths to few mg/L in acidic soils
Molybdenum	0.01	Nontoxic to plants; can be toxic to livestock if forage is grown in soils with high molybdenum
Nickel	0.2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH
Selenium	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium
Tin, Tungsten, and Titanium	-	Excluded by plants; specific tolerance levels unknown
Vanadium	0.1	Toxic to many plants at relatively low concentrations
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils

7.4 WHO water quality guidelines for irrigation

Parameter		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Salinity Ecwa		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_H	0_3	meq/l	>0.7 ECw	0.7-0.2 Ecw	<0.2 Ecw
SAR	3_6	meq/l	>1.2ECw	1.2-0.3ECw	<0.3ECw
SAR	6_12	meq/l	>1.9ECw	1.9-0.5 ECw	<0.5ECw
SAR	12_20	meq/l	>2.9 ECw	2.9-1.3ECw	<1.3ECw
SAR	20_40	meq/l	>5.0ECw	5.0-2.9ECw	<2.9ECw
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
Chlorine(Cl2)	Total residual	mg/l	<1	1_5	>5
Bicarbonate(HCO3)		mg/l	<90	90_500	>500
Boron(B)		mg/l	<0.7	0.7_3.0	>3.0
Hydrogen sulfide(H2S)		mg/l	<0.5	0.5_2.0	>2.0
Iron(Fe)	Drip irrigation	mg/l	<0.1	0.1_1.5	>1.5
Mangnanese(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					
TDS, total dissolved solids: TSS, total suspended solids					

Sources: Ayers&Westeot (1985): Pescod (1992): Asano and Levine (1998)

[a] means Electrical conductivity in deciSiemens per metre at 25^0 C

[b] SAR means sodium absorption ratio [(meq/l)]$^{1/2}$

7.5 SAR ratio & log reduction

- The Sodium adsorption ratio is an irrigation water quality parameter used in the management of sodium-affected soils.
- It is an indicator of the suitability of water for use in agricultural irrigation, as determined from the concentrations of the main alkaline and earth alkaline cations present in the water.
- 1 log reduction means the number of germs is 10 times smaller
- 2 log reduction means the number of germs is 100 times smaller
- 3 log reduction means the number of germs is 1000 times smaller
- 4 log reduction means the number of germs is 10,000 times smaller
- 5 log reduction means the number of germs is 100,000 times smaller
- 6 log reduction means the number of germs is 1,000,000 times smaller
- 7 log reduction means the number of germs is 10,000,000 times smaller

7.6 Health based Targets for wastewater use in agriculture, (WHO

Exposure Scenario	**Health based target (Daily per person per year)**	**Log_{10} pathogen reduction needed**	**Number of helminth eggs per litre**
Unrestricted irrigation	$\leq 10^{-6}$ [a]		
Lettuce		6	≤ 1 [b,c]
Onion		7	≤ 1 [b,c]
Restricted irrigation	$\leq 10^{-6}$ [a]		
Highly mechanized		3	≤ 1 [b,c]
Labour intensive		4	≤ 1 [b,c]
Localized (drip) irrigation	$\leq 10^{-6}$ [a]		
High growing crops		2	Not recommended

The tolerable burden of disease is defined as an upper limit of 10-6 DALYs per person per year. This upper limit DALY is approximately equivalent to a 10-5 excess lifetime risk of cancer (i.e. 1 excess case of cancer per 100,000 people ingesting drinking water at the water quality target daily over a 70 year period)

7.7 Treated wastewater quality for irrigation according to EPA, WHO,EU & ISO

	EPA	**WHO**		**ISO**	**EU**
PARAMETERS	Non food crops	Un-restricted	restricted	Non food crops	Non food crops Drip irrigation only
BOD5 (mg/l)	≤30	-	-	≤20-35	≤25
TSS (mg/l)	≤30	-	-	≤30-50	≤35
E-COLI cfu/100ml	≤200	≤1000	≤10,000	≤1000-10,000	≤1,000
Helminthes (eggs/100 cm3)	-	≤1	≤1	≤1	≤1

7.8 Comparison of TDS

Parameter	US EPA	US EPA	WHO	EU
	Restriction	No restriction	Slight to moderate restrictions	Slight to moderate restrictions
TDS (mg/l)	< 450	175	450 – 2000	525

7.9 UN FAO guidelines for the agricultural reuse of treated water

The Food and Agriculture Organization of the United Nations

Type of Agricultural Reuse	Type of Treatment	Quality Criterion
Agricultural reuse in crops that are **consumed and not processed commercially.**	Secondary Filtration—Disinfection	**BOD < 10 mg/L** <2 UNT <14 NMP E. coli/100 mL <1 Egg/L
Agricultural reuse in crops that are consumed and processed commercially.	Secondary—Disinfection	**BOD < 30 mg/L** SS < 30 mg/L <200 NMP E. coli/100 mL
Agricultural reuse in crops that are not consumed.	Secondary—Disinfection	**BOD < 30 mg/L** SS < 30 mg/L <200 NMP E. coli/100 mL

7.10 Irrigation reuse of treated wastewater in Pakistan

- For effluent reuse, the NEQS requires a 10 times dilution of the treated effluent.
- NEQS have no standards for coliforms.
- The Manual of Irrigation Practice provides no data on discharge standards for irrigation
- Irrigation Water Quality Guidelines" (2007) prepared by WWF proposed 1000/100mL for faecal coliforms in irrigation water.
- The World Health Organization also proposed the faecal coliform as 1000/100mL for irrigation water.

7.11 Draft Punjab environment standards for irrigation water

Parameter	Unit	Proposed Standard
TDS	mg/l	1000
BOD	mg/l	8
Coliform bacteria (fecal)	No./100mL	1000
Aluminum	mg/l	5
Arsenic	mg/l	0.1
Cadmium	mg/l	0.01
Chromium	mg/l	0.01
Flouride	mg/l	1
Iron	mg/l	5
Toxic substances and organic pollutants		The water should not contain toxic substances and other organic compounds in quantities that can accumulate in the soils to such a level as to result in the uptake by the crop and thus may be detrimental to public health or impair the quality of water for use in agriculture and livestock watering.

7.12 How to meet irrigation standards

- If effluent of a WWTP meet the NEQ standards (BOD of 80mg/L), and a 10:1 dilution to the water body (Irrigation canal), then this would meet the levels required for irrigation water use (BOD of 8mg/L).
- For direct use of treated wastewater effluent quality of BOD may be of 8mg/L
- Currently there are no standards for faecal coliform limit
- However if it required as recommended in Draft Punjab Environmental quality standards, if the WWTP effluent meet a faecal coliform limit of 10,000/100mL, with a 10:1 dilution, then this would meet the levels required for irrigation water use (faecal coliforms of 1000/mL).
- For direct reuse disinfection may be required

References:

- *WHO A compendium of standards for wastewater reuse in the Eastern Mediterranean Region*
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- *Environmental and public health implications of wastewater quality.pdf*
- *71853495-Manual-of-Irrigation-Practice-MIP-Volume-I-Revised-2017.pdf*
- *JRC Science for Policy Report:Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge*
- *WWF Irrigation Water Quality Guidelines for Pakistan*
- *Annika Kramer and Julika Post Adelphi Reseach Berlin Guidelines and Standards for Wastewater Reuse*

US EPA Guidelines for water reuse 2012