Irrigation Water Quality Guidelines

Revised Version
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gtz Jordanian - German Water Program

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Jordan's *Irrigation Water Quality Guidelines* were modified and revised in 2006 by an interdisciplinary working group consisting of the Jordan Valley Authority (JVA), the Water Authority of Jordan (WAJ), the National Center for Agricultural Research and Technology Transfer (NCARTT), Ministry of Health (MoH), the Ministry of Agriculture (MoA), the Ministry of Environment (MoEnv), the Royal Scientific Society (RSS) and senior academics from a number of Jordanian Universities, with the German Technical Cooperation (GTZ) serving as a facilitator.

تم تعديل وتحديث ومراجعة هذا الدليل في عام ٢٠٠٦ من قبل مجموعة عمل تضم مختصين من وزارة المياه والري وسلطة وادي الأردن و سلطة المياه و المركز الوطني للبحوث الزراعية ونقل التكنولوجيا و وزارة الصحة و وزارة الزراعة و وزارة البيئة والجمعية العلمية الملكية وبعض أساتذة الجامعات الأردنية وبدعم ومساهمة من الوكالة الألمانية للتعاون الفني.

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Introduction

Jordanian-Germany Water Program, jointly implemented by the Jordan Valley Authority (JVA) and German Technical Cooperation (GTZ), updated the Irrigation Water Quality Guidelines in 2006 to suit Jordanian irrigation water quality conditions. Jordan's agricultural sector is a vital economic sector and consumes 65% of the country's available water resources. As Jordan has a number of different water sources with different water qualities that have a varying impact on plants, soils and human health, it was necessary to delineate Jordanian recommendations that could ensure safe and sustainable use for irrigation water.

As the Jordanian Standard (893:2002) for reclaimed domestic wastewater is concerned only with effluent from wastewater treatment plants, does not allow diluting or mixing this water with other fresh water sources and allows use only for restricted irrigation, these modified guidelines take into consideration all water sources other than those mentioned in the Jordanian Standard 893. Furthermore the guidelines cover all unrestricted agricultural crops.

These modified Irrigation Water Quality Guidelines were updated by subject matter specialists in the field of water quality and also take into consideration regional and international regulations and standards.. Furthermore, several international references were reviewed and adapted in order to developed guidelines appropriate to Jordanian conditions that can serve as the foremost guidelines dealing with irrigation water quality in Jordan.

I would to express my deep gratitude to the German Technical Cooperation for its continued support to the water sector. Thanks are also extended to all our colleagues who contributed to reviewing these guidelines.

Secretary General of Jordan Valley Authority
Eng. Musa Dafi Al-Jamani

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1. Abbreviations

Al	Aluminium
As	Arsenic
B	Boron
Be	Beryllium
BOD_5	Biochemical Oxygen Demand (amount of oxygen required to oxidize organic matter in 5 days of incubation)
Br	Bromide
Ca	Calcium
Cd	Cadmium
Cl	Chloride
Co	Cobalt
COD	Chemical Oxygen Demand (amount of oxygen required to oxidize inorganic and organic matter)
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
EC	Electrical Conductivity
E.coli	Escherichia coli
F	Fluoride
Fe	Iron
FOG	Fat, Oil and Grease
HCO_3	Bicarbonate
Hg	Mercury
K	Potassium
Li	lithium
meq/l	milli-equivalent per liter
Mg	Magnesium
mg/l	milligrams per liter
Mn	Manganese
Mo	Molybdenum
Na	Sodium
NH_4	Ammonium
Ni	Nickel
Ni	Nickel
NO_3	Nitrate
P	Phosphorous
Pb	Lead
pH	Negative logarithm of H^+ concentration
SAR	Sodium Adsorption Ratio (SAR = Na / ((Ca + Mg) $^{0.5}$/2))
Se	Selenium
SO_4	Sulfate
TDS	Total Dissolved Solids
T-N	Total Nitrogen
TSS	Total Suspended Solids
Turbidity	Is a measure of the cloudiness of water
V	Vanadium
Zn	Zinc

2. Summary Table

Parameter	Unit	Limit Value	Parameter	Unit	Limit Value
pH		6 - 9	**NH_4-N**	mg/l	< 16
EC			**T-N**	mg/l	< 50
- *Salt sensitive*	dS/m	< 1.7	**SO_4**	mg/l	< 960
- *Medium salt tolerant*	dS/m	1.7 - 3	**B**		
- *Salt tolerant*	dS/m	3 - 7.5	- *Boron sensitive*	mg/l	0 - 0.7
- *Highly salt tolerant*	dS/m	> 7.5	- *Moderately Boron sensitive*	mg/l	0.7 - 1.5
TSS	mg/l	< 50	- *Moderately Boron tolerant*	mg/l	1.5 - 3
BOD_5	mg/l	< 60	- *Boron tolerant*	mg/l	3 - 6
COD	mg/l	< 120	**Fe**	mg/l	< 1
Ca	mg/l	< 400	**Mn**	mg/l	< 2
Mg	mg/l	< 150	**Zn**	mg/l	< 2
SAR		6 - 9	**Cu**	mg/l	< 1
K	mg/l	< 80	**E.coli**	MPN/ 100 ml	1000/100 ml
HCO_3	mg/l	< 520	**Intestinal nematodes**	Eggs/ liter	≤ 1
NO_3-N	mg/l	< 16			

3. Scope

These Irrigation Water Quality Guidelines deal with irrigation water that includes brackish water, surface and ground water and blended water[1] that can be used in unrestricted irrigation.
The suitability of water for irrigation depends on a variety of factors. The most relevant and important are:

1. concentration of Total Dissolved Solids (TDS) in irrigation water (expressed in EC units), which mainly affects crop yields,
2. concentration of certain ions, which may be toxic to plants or have unfavourable effects on crops, soils and public health,
3. concentration of cations, which may cause de-flocculation of clays in soils resulting in damage to soil structure and permeability (SAR),
4. pathogens, which may affect the health of humans and animals consuming contaminated crops or coming into contact with pathogens-contaminated water.
5. others, including climatic factors.

The suitability of water for irrigation varies according to crops, types and permeability of soils and climate. Therefore, neither universal guidelines nor absolute standards for irrigation water quality can be formulated. What might be seen as poor irrigation water quality in one area or for a certain crop could be very suitable in other areas or for other crops.
In addition, special farming and irrigation techniques have been developed that allow for water of marginal quality to be used in productive agriculture. These include the use of drip irrigation, leaching, plastic mulch, green houses, salt tolerant crops and disinfection of soils and irrigation water.
The relevant properties of a water source for use in irrigation can be subdivided into physical, chemical, biochemical and micro-biological properties.

The physical, chemical and biochemical parameters are:

* pH value
* EC
* Temperature
* Turbidity, TSS
* DO
* BOD_5, COD, Ca, Mg, SAR, Na, Cl, K, HCO_3, NO_3, SO_4, P
* Trace elements / Heavy metals: B, Fe, Mn, Zn, Cu, Pb, Cd, Hg, Cr, Ni
* Organic compounds: FOG, phenols.

The micro-biological parameters are:

* Faecal Coliforms or Escherichia coli and
* Intestinal Helminthes eggs.

[1] Blended Water: Mixture or dilution of fresh water and reclaimed water.

If we consider the quality of irrigation water in Jordan and the general impact of irrigation water on plants, soils, groundwater, human and animal health, we find that the increase of salt concentration (TDS), Sodium Adsorption Ratio (SAR), Boron concentration (B) and pathogens beyond the allowed limits is the most important factors affecting the safe use of irrigation water and crop productivity.

4. Impact of Parameters

pH value

Water with pH 6.0 to 9.0 generally has no significant negative impact on plants or soils. The main pH impact is on nutrient availability for plants and in addition on irrigation equipment, which could corrode or may develop a scale or precipitation of carbonates. As most soils in Jordan are alkaline, lower pH values could influence plant growth positively.

Salinity

Salt concentration and composition of irrigation water are the main factors determining the suitability of crops, together with other factors such as soil and climate. The different types of plants can only tolerate a certain salt content of irrigation water, expressed generally in Electrical Conductivity units (dS/m). Plants are classified into four categories: sensitive, salt moderately sensitive, salt tolerant plants and salt highly tolerant plants. Annex A shows crop tolerance and yield potentials of selected crops as influenced by irrigation water salinity.

- Salt sensitive: EC < 1.7 dS/m
  e.g. citrus, carrot, strawberry, onion.

- Salt moderately sensitive : EC between 1.7 and 3.0 dS/m
  e.g. olive, pepper, cucumber, cauliflower, lettuce, watermelon, cabbage, grapes.

- Salt tolerant: EC between 3.0 and 7.0 dS/m
  e.g. asparagus, date palm, barley, wheat.

- Salt highly tolerant: EC ≥ 7.5 dS/m
  e.g. trees (tamarisk, cinchona, casuarina, acacia).

This does not mean a salt sensitive plant cannot tolerate being irrigated with a water of higher than 1.7 dS/m, but it does means that the productivity of that specific plant will decline by a certain percentage if irrigated with higher salinity water.
Generally, exceeding the upper limits of salinity tolerance for the different crops by 30% could possibly result in a productivity decline of about 10%.

Irrigation water contains a mixture of naturally occurring salts. Soils irrigated with this water will contain a similar mix but usually at a higher concentration than in the applied water. The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management, the adequacy of drainage and the amount of precipitation. If salts become excessive, losses in yield will result. To prevent yield loss salts in the soil must be controlled at a concentration below that which might affect yield. Annex B shows approximate pre-irrigation requirements to leach salts in the upper 0.3 m for different soil types at three levels of salinity (EC_e).

Temperature

Generally, irrigation water should have a temperature of between 4°C to 30°C.

Turbidity and Total Suspended Solids (TSS)

As physical parameters, Turbidity and TSS may reduce soil surface permeability or may cause clogging of micro irrigation systems if filtration does not exist or regular maintenance is not carried out. Suspension and turbidity are caused by fine soil and rock particles, remains of organic matter and iron oxides, bicarbonate particles and others.

However, a concentration of total suspended solids in irrigation water of more than 50 mg/l can have physical and maybe chemical impacts on irrigation systems, such as clogging, precipitating and calcinations. When using sprinkler irrigation the suspended solids will precipitate on leaves and fruits, leading to a decrease in product quantity and poor crop quality.

Biochemical/Chemical Oxygen Demand (BOD_5, COD)

Oxygen is necessary for plant growth and it must be present in the root zone or plants will suffer. However, anaerobic situations will occur only if irrigation water contains high organic matter concentrations and very low Dissolved Oxygen (DO) contents at the same time. When soils remain 100% saturated with that water for long periods of time, it allows the development of the described negative anaerobic conditions in the root zone and its surroundings.
Values of up to 60 mg/l for BOD_5 and up to 120 mg/l for COD cannot be considered as harmful to plants or soils.

Calcium (Ca) and Magnesium (Mg)

The action of Ca and Mg on soils and plants is directly connected to the pH value and concentration of Na as explained below (see SAR, Na and Cl).
Ca concentration of less than 400 mg/l and Mg concentration of less than 150 mg/l in irrigation water is recommended.

Sodium Adsorption Ratio (SAR)

When the SAR value is less than 6, no problems are to be expected for soils or plants. SAR of 6 - 9 may cause some problems to soils, such as a decrease soil permeability. SAR of more than 9 may cause clogging of soils. The concentration of sodium and calcium are expressed in milliequivalents per liter (meq/l). The SAR can be used in conjunction with the salinity of the applied irrigation water (EC_{iw}) to assess potential permeability problems as shown in annex C.

Sodium (Na) and Chloride (Cl)

Generally, the effects of Na and Cl are bound to the Ca content of the soil: the higher the Ca content, the less the negative impacts of Na and Cl. Na and Cl are the major salinity parameters in irrigation water.
Because of the above mentioned two reasons, the Sodium Adsorption Ratio (SAR) was developed to determine the suitability of water for irrigation. Excessive Na in irrigation water promotes soil dispersion and structural breakdown.

Potassium (K)

The available potassium in irrigation water is usually used as fertilizer. Only at very high concentrations (> 80 mg/l) does it reduce plant uptake of Ca.

Bicarbonate (HCO_3)

HCO_3 in concentrations of less than 520 mg/l are not known to have negative impacts on plants and soils.

Nitrogen Compounds

1. Nitrate (NO_3) and Ammonium (NH_4)

NO_3 and NH_4 serve as a nutrient for plants but excessive concentrations may cause delayed maturity or poor crop quality. NO_3 can also be reduced into gaseous nitrogen that escapes into the atmosphere. A maximum level of 16 mg/l NO_3-N or NH_4-N for irrigation water is recommended.

2. Total Nitrogen

Nitrogen is considered to be one of the major nutrients for plant growth. High nitrogen concentration in irrigation water may cause excessive vegetative growth and delay in crop maturity. Generally, total nitrogen consists of nitrate (NO_3), Nitrite (NO_2) ammonium (NH_4) and organic nitrogen. A maximum level of 50 mg/l as total nitrogen for irrigation water is recommended.

Sulfate (SO_4)

In natural water SO_4 is not known to cause any harm to plants because it is generally of low solubility and it precipitates in soils. Generally, concentrations in irrigation water may go up to 960 mg/l without major effects on plants or soils.

When using sprinkler irrigation, gypsum crystals will precipitate on leaves and fruits and if SO_4 concentration exceeds 300 mg/l it may cause damage to leaves and fruits.

Phosphorous (P)

P is an essential element for plant growth. It is not known that the total P concentration in irrigation water can cause any adverse effects on plants and soils. PO_4 can be absorbed by plants or fixed in the soil horizons in the presence of Fe, Al and Ca.

Boron (B)

B is an essential micro-nutrient for plant growth but excessive concentration of Boron in irrigation water will adversely affect the plant. Plants are classified into 4 categories according to their sensitivity to boron in irrigation water. Examples for plants that are relevant in Jordan are:

- Boron sensitive 0 – 0.7 mg /l
  e.g. lemon, wheat, strawberry, peach, grape, onion, garlic, bean

- Boron moderately sensitive 0.7 – 1.5 mg /l
  e.g. pepper, carrot, potato, cucumber

- Boron moderately tolerant 1.5 – 3 mg /l
  e.g. lettuce, cabbage, corn, celery, squash, watermelon, tobacco

- Born tolerant 3 – 6 mg /l
  e.g. alfalfa, parsley, tomato, asparagus

Trace Elements / Heavy Metals

Fe, Mn, Zn, Cu and others are essential for plant growth however, if their concentrations exceed certain limits, plants will suffer and their productivity will be reduced.
Soils are generally good traps for trace elements and heavy and can tolerate irrigation water with high concentrations of them for tens of years. Within the soils they form insoluble salts or complexes.

* Iron (Fe) in the presence of oxygen is not harmful to plants because it is readily oxidized to insoluble iron. Therefore, Fe in irrigation water precipitates in soils. Concentrations in irrigation water up to 1 mg/l are not found to harm plants or soils.

* Manganese (Mn) is an essential trace element. Up to 2 mg/l in irrigation water is not expected to cause any harm to plants in the alkaline soils in Jordan.

* Zinc (Zn) is an essential micro-nutrient. Concentrations in soils may reach a few hundred mg/kg before any negative effect takes place. Therefore, up to 2 mg/l of Zn in irrigation water will not cause any negative effects on plants or soils.

* Copper (Cu) is also an essential element for plant growth and plant survival. Hence Cu concentrations in irrigation water up to 1 mg/l will not produce any negative impacts on plants and soils.

Some heavy metals in concentrations of a few tens of micrograms per liter in irrigation water are not known to cause harm to plants or soils. However, if sprinkler irrigation is used, heavy metals may accumulate on leaves and fruits and may be adsorbed by them, which means deteriorating product quality and health risk to consumers. Annex D shows recommended maximum concentrations of trace elements in irrigation water.

Pathogens

Pathogens present a risk to human public health and animal health through exposure by contact, inhalation or ingestion. Therefore, irrigation water containing treated wastewater may contain pathogens that could be hazardous to farm staff and the public if certain protection practices are not applied.

Soil acts to remove pathogens. The removal efficiency depends on a variety of factors, including the physical and biological characteristics of soil and the surrounding environment conditions. Protozoa and helminthes can be removed effectively by filtration, bacteria by adsorption and viruses by sorption to soil particles.

Temperature is also considered to be a main factor affecting the survival of pathogens. Low temperatures (around $4^{o}C$) already allow bacterial survival for a long time and the growth rate doubles with each $10^{o}C$ increase in temperature.

As a consequence of the above mentioned factors, a limitation on pathogens for irrigation water in general is not recommended.

However, in cases where irrigation water contains reclaimed water a limit of maximum 1 Intestinal Helminthes egg per liter is suggested. In addition, a maximum of 1,000 Faecal Coliforms or Escherichia coli as geometric mean number per 100 ml is recommended.

Recommended microbiological guidelines for blended water use in agriculture are given in annex E.

Organic compounds

Organic compounds are degraded chemically in the soil by hydrolysis, photo-decomposition or redox-reactions. Microbiological conversion occurs mainly in the upper layers of soils.

5. Monitoring

Irrigation with water that does not comply with these *Irrigation Water Quality Guidelines* might lead in the long run to a decrease of agricultural production and negative impacts on groundwater, soils and human or animal health.

The relevant organizations in the field of irrigation water, in particular the Jordan Valley Authority, the Water Authority of Jordan and the Higher Council for Science and Technology, each one according to its responsibility, are monitoring the quality of irrigation water sources through regular parameter analysis. These monitoring programs should be integrated in order to develop a national program in this field.

The parameters type and the frequency of irrigation water quality monitoring programs depend on the characteristics of location and changes in irrigation water quality. For some time, the Jordan Valley Authority has been conducting irrigation water monitoring programs in the Jordan Valley, the Jordan and Yarmouk Rivers, Reservoirs, the King Abdullah Canal, Side Wadis and other water sources where physical, chemical and biological parameters are analysed on daily, monthly and semi-annual basis.

Cheap portable equipment available in local market could be used to verify the suitability of the salinity (EC) and alkalinity (pH) of irrigation water. Farmers, and particularly those who deal with several irrigation water sources, could used this equipment.

It is hoped that all relevant organizations and water laboratories will apply these guidelines alongside other references to evaluate the quality of irrigation water.

Annex A

Crop Tolerance and Yield Potential of selected Crops as influenced by Irrigation Water Salinity (ECiw).Adapted from Maas and Hoofman (1977) and Mass (1984) in: Ayers and Westcot, 1985.

Yield Potential						
Field Crops Common Name	**Botanical Name**	100% EC_{iw}	90% EC_{iw}	75% EC_{iw}	50% EC_{iw}	0% EC_{iw}
Barley	*Hordeum vulgare*	5.3	6.7	8.7	12	19
Sugarbeet	*Beta vulgaris*	4.7	5.8	7.5	10	16
Sorghum	*Sorghum bicolor*	4.5	5	5.6	6.7	8.7
Wheat	*Triticum aestivum*	4	4.9	6.3	8.7	13
Wheat, Durum	*Triticum turgidum*	3.8	5	6.9	10	16
Soybean	*Glycine max*	3.3	3.7	4.2	5	6.7
Cowpea	*Vigna unguiculata*	3.3	3.8	4.7	6	8.8
Sugarcane	*Saccharum officinarum*	1.1	2.3	4	6.8	12
Corn	*Zea mays*	1.1	1.7	2.5	3.9	6.7
Broadbean	*Vicia faba*	1.1	1.8	2	4.5	8
Bean	*Phaseolus vulgaris*	0.7	1	1.5	2.4	4.2
Vegetable Crops						
Squash, zucchini	*Cucurbita pepo melopepo*	3.1	3.8	4.9	6.7	10
Beet, red	*Beta vulgaris*	2.7	3.4	4.5	6.4	10
Squash, scallop	*C. pepo melopepo*	2.1	2.6	3.2	4.2	6.3
Broccoli	*Brassica oleracea botrytis*	1.9	2.6	3.7	5.5	9.1
Tomato	*Lycopersicon esculentum*	1.7	2.3	3.4	5	8.4
Cucumber	*Cucumis sativus*	1.7	2.2	2.9	4.2	6.8
Spinach	*Spinacia oleracea*	1.3	2.2	3.5	5.7	10
Celery	*Apium graveolens*	1.2	2.3	3.9	6.6	12
Cabbage	*B. oleracea capitata*	1.2	1.9	2.9	4.6	8.1
Potato	*Solanum tuberosum*	1.1	1.7	2.5	3.9	6.7
Corn, sweet	*Zea mays*	1.1	1.7	2.5	3.9	6.7
Sweet potato	*Ipomoea batatas*	1	1.6	2.5	4	7.1
Pepper	*Capsicum annuum*	1	1.5	2.2	3.4	5.8
Lettuce	*Lactuca sativa*	0.9	1.4	2.1	3.4	6
Radish	*Raphanus sativus*	0.8	1.3	2.1	3.4	5.9
Onion	*Allium Cepa*	0.8	1.2	1.8	2.9	5
Carrot	*Daucus carota*	0.7	1.1	1.9	3	5.4
Bean	*Phaseolus vulgaris*	0.7	1	1.5	2.4	4.2
Turnip	*Brassica rapa*	0.6	1.3	2.5	4.3	8
Forage Crops						
Wheatgrass, tall	*Agropyron elongatum*	5	6.6	9	13	21
Wheatgrass, fairway crested	*A. cristatum*	5	6	7.4	9.8	15
Barley (forage)	*Hordeum vulgare*	4	4.9	6.4	8.7	13
Ryegrass, perennial	*Lolium perenne*	3.7	4.6	5.9	8.1	13
Vetch, common	*Vicia angustifolia*	2	2.6	3.5	5	8.1
Clover, berseem	*Trifolium alexandrinum*	1	2.2	3.9	6.8	13
Orchardgrass	*Dactylis glomerata*	1	2.1	3.7	6.4	12
Foxtail, meadow	*Alopecurus pratensis*	1	1.7	2.7	4.5	7.9

Yield Potential						
Common Name **Forage Crops**	**Botanical Name**	100% EC_{iw}	90% EC_{iw}	75% EC_{iw}	50% EC_{iw}	0% EC_{iw}
Clover, ladino	*Trifolium repens*	1	1.6	2.4	3.8	6.6
Clover, strawberry	*Trifolium fragiferum*	1	1.6	2.4	3.8	6.6
Fruit Crops						
Date palm	*Phoenix dactylifera*	2.7	4.5	7.3	12	21
Grapefruit	*Citrus paradisi*	1.2	1.6	2.2	3.3	5.4
Orange	*Citrus sinensis*	1.1	1.6	2.2	3.2	5.3
Peach	*Prunus persica*	1.1	1.5	1.9	2.7	4.3
Apricot	*Prunus armeniaca*	1.1	1.3	1.8	2.5	3.8
Grape	*Vitis* sp.	1	1.7	2.7	4.5	7.9
Almond	*Prunus duclis*	1	1.4	1.9	2.8	4.5
Plum, Prune	*Prunus domestica*	1	1.4	1.9	2.9	4.7
Blackberry	*Rubus sp*	1	1.3	1.8	2.5	4
Strawberry	*Fragaria* sp.	0.7	0.9	1.2	1.7	2.7

Annex B

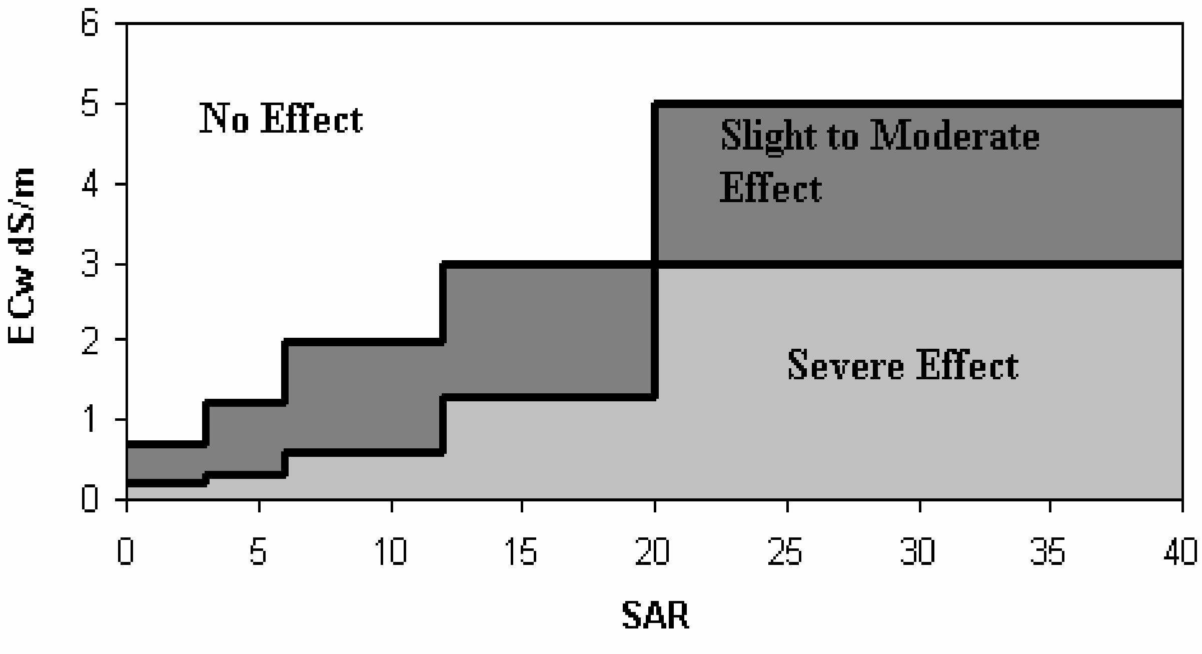
Approximate pre-irrigation requirements to leach salts in the upper 0.3 m for different soil types at three levels of soil salinity to reduce EC_e to 2 dS/m.

Soil Type	Water content at field capacity (mm) in 0.3 m depth	Pre-irrigation (mm) $EC_e = 4$	Pre-irrigation (mm) $EC_e = 10$	Pre-irrigation (mm) $EC_e = 20$
Sandy	27	42	57	87
Loamy sand	38	53	68	98
Sandy loam	62	77	92	122
Loam	81	96	111	141
Silt loam	99	114	129	159
Sandy Clay loam	77	92	107	137
Clay Loam	95	110	125	155
Silt Clay loam	110	125	140	170
Sandy Clay	102	117	132	162
Silt clay	116	131	146	176
Clay	119	134	149	179

Source: adjusted from Western fertilizer handbook, 2002.

Annex C

Influence of Irrigation Water Salinity (EC_w) and SAR levels on Soil permeability (Asano, 1998. Adapted from Ayers and Westcott, 1989).



Degree of Effect	ECw (dS/m)	SAR
No Effect	0.7 - 1.2	0 - 3
	1.2 - 2	3 - 6
	2 - 3	6 - 12
	3 - 5	12 - 20
	5 - 6	20 - 40
Slight to Moderate	0.2 - 0.3	0 - 3
	0.3 - 0.6	0 - 6
	0.6 - 0.7	0 - 12
	0.7 - 1.2	3 - 12
	1.2 - 2	6 - 20
	2 - 3	12 - 20
	3 - 5	20 - 40
Severe	0 - 0.2	0 - 40
	0.2 - 0.3	3 - 40
	0.3 - 0.6	6 - 40
	0.6 - 1.3	12 - 40
	1.3 - 3	20 - 40

Annex D
Recommended Maximum Concentration of Trace Elements in Irrigation Water[1]

Element	Recommended Maximum Concentration[2] (mg/l)	Remarks
Al (aluminium)	5	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.1	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.1	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.1	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
F (fluoride)	1	Inactivated by neutral and alkaline soils.
Li (lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni (nickel)	0.2	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pb (lead)	5	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
V (vanadium)	0.1	Toxic to many plants at relatively low concentrations.

[1] Adapted from National Academy of Sciences (1972) and Pratt (1972).

[2] The maximum concentration is based on a water application rate that is consistent with good irrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

Annex E

The following WHO (2000) table can serve as orientation with regard to microbial guidelines.

Category	Reuse conditions	Exposed group	Irrigation technique	Intestinal nematodes[b] (arithmetic mean no. of eggs per litre[c])	Faecal coliforms (geometric mean no. per 100 ml[d])	Wastewater treatment expected to achieve required microbiological quality
A	Unrestricted irrigation					Well-designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g., conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)
	A1 For vegetable and salad crops eaten uncooked, sports fields, public parks[e]	Workers, consumers, public	Any	$\leqslant 0.1$[f]	$\leqslant 10^3$	
B	Restricted irrigation					
	Cereal crops, industrial crops, fodder crops, pasture and trees[g]	B1 Workers (but no children <15 years), nearby communities	Spray or sprinkler	$\leqslant 1$	$\leqslant 10^5$	Retention in WSP series including one maturation pond or in sequential WSTR or equivalent treatment (e.g., conventional secondary treatment supplemented by either polishing ponds or filtration)
		B2 as B1	Flood/furrow	$\leqslant 1$	$\leqslant 10^3$	As for Category A
		B3 Workers including children <15 years, nearby communities	Any	$\leqslant 0.1$	$\leqslant 10^3$	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	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms; the guideline limit is also intended to protect against risks from parasitic protozoa.

[c] During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve these egg numbers, then routine effluent quality monitoring is not required).

[d] During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly).

[e] A more stringent guideline limit ($\leqslant$ 200 faecal coliforms/100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[f] This guideline limit can be increased to $\leqslant$ 1 egg/l if (i) conditions are hot and dry and surface irrigation is not used or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater reuse.

[g] In the case of fruit trees, irrigation should stop two weeks before fruit is picked, and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used.

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