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Effluent Quality Parameters for Safe use in Agriculture

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1. Introduction

"When the well is dry, we know the worth of water."
Benjamin Franklin, (1706-1790), Poor Richard's Almanac, 1746

Fast depletion of groundwater reserves, coupled with severe water pollution, has put governments all over the world in a difficult position to provide sufficient fresh water for our daily use. Ismail Serageldin vice president of World Bank in 1995 predicted that "if the wars of this century were fought over oil, the wars of the next century will be fought for water". Thus it signifies the role water is going to play in the current century we live in. At the same time, the need for sustained food production to feed the hungry mouths of the ever increasing population is apparent. In many arid and semi-arid countries since water is becoming increasingly scarce resource and planners are forced to consider alternate sources of water which might be used economically and effectively. The use of wastewater (WW) for crop irrigation as an alternative for effluent water disposal and for freshwater (FW) usage is common worldwide in countries in which water is scarce. Disposal of wastewater is also a problem of increasing importance throughout the world including India. Both the need to conserve fresh water and to safe and economically dispose of wastewater makes its use in agriculture a very feasible option. Furthermore, wastewater reuse may reduce fertilizer rates in addition to low cost source of irrigation water. In many parts of the world, treated municipal wastewater and raw sewage wastewater and even industrial wastewater has been successfully used for the irrigation of various crops (Asano and Tchobanoglous 1987, Adriel et al., 2007; Tak et al., 2010). It is well known that the enteric diseases, anaemia and gastrointestinal illnesses are high among sewage wastewater farmers. In addition, the consumers of vegetable crops which are eaten uncooked and grown without any treatment are also at risk. This chapter particularly envisages the review on the safe and quality parameters of wastewater for sustainable use in agriculture.

The use of sewage effluents for agricultural irrigation is an old and popular practice in agriculture (Feigin et al., 1984). Irrigation with wastewater has been used for three purposes:

i. complementary treatment method for wastewater (Bouwer & Chaney, 1974);
ii. use of marginal water as an available water source for agriculture (Al-Jaloud et al., 1995; Tanji, 1997) – a sector demanding ~ 70% of the consumptive water use.

iii. use of wastewater as nutrient source (Bouwer & Chaney, 1974; Vazquez- Montiel et al., 1996) associated with mineral fertilizer savings and high crop yields (Feigin et al., 1991; Tak et al., 2010).

Irrigated agriculture is dependent on an adequate water supply of usable quality. Water quality concerns have often been neglected and the situation is now changing in many areas. To avoid problems when using these poor quality water supplies, there must be sound planning to ensure that the quality of water available is put to the best use. The objective of this article is to help the reader in better understanding of the effect of water quality upon soil and crops and to assist in selecting suitable alternatives to cope with potential water quality related problems that might reduce production under prevailing conditions of use. Thus knowledge of irrigation water quality is critical in understanding management for its long-term usage and productivity. Conceptually, water quality refers to the characteristics of water that will influence its suitability for a specific use, i.e. how well the quality meets the needs of the user. Quality is defined by certain physical, chemical and biological characteristics. Even a personal preference such as taste is a simple evaluation of acceptability. For example, if two drinking waters of equally good quality are available, people may express a preference for one supply rather than the other; the better tasting water becomes the preferred supply. In irrigation water evaluation, however, the emphasis is placed on the chemical and physical characteristics of water and only rarely is any other factor considered important. There have been a number of different water quality guidelines related to use of wastewater in agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in field conditions. The guidelines presented in this paper have also relied on previous ones but are modified for evaluating and managing water quality-related problems of irrigated agriculture.

2. Irrigation water quality criteria

Soil scientists use various physico chemical parameters to describe irrigation water effects on crop production and soil quality. These include, Salinity hazard - total soluble salt content, Sodium hazard - relative proportion of sodium to calcium and magnesium ions, pH - acidic or basic, Alkalinity - carbonate and bicarbonate, Specific ions: chloride, sulfate, boron, and nitrate. However, another potential irrigation water quality parameter that may affect its suitability for agricultural system is microbial pathogens, which has often been neglected.

2.1 Salinity hazard /electrical conductivity

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (EC_w). The primary effect of high EC_w water on crop productivity is the inability of the plant to compete with ions in the soil solution for water a condition known as Osmotic drought (physiological drought). Higher the EC, lesser is the water available to plants, even though the soil may appear to be wet. Because plants can only transpire "pure" water, usable plant water in the soil solution decreases dramatically as EC increases. An actual yield reduction from irrigation with high EC water varies substantially. Factors influencing yield reductions include soil type, drainage, salt type, irrigation system and management. The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high EC_w reduces yield potential (Table 1). Beyond effects on the immediate crop is the long term impact of salt loading through the irrigation water. Water with an EC_w of only 1.15 dS/m contains approximately 2,000 pounds of salt for every acre foot of water. You can use conversion factors in Table 2 to make this calculation for other water EC levels.

Limitations for use	Electrical Conductivity
	(dS/m)*
None	≤0.75
Some	0.76 - 1.5
Moderate[1]	1.51 - 3.00
Severe[2]	≤3.00

*dS/m at 25ºC=mmhos/cm
[1]Leaching required at higher range.
[2]Good drainage needed and sensitive plants may have difficulty at germination.

Table 1. General guidelines for salinity hazard of irrigation water based upon conductivity.

Salt-affected soils develop from a wide range of factors including: soil type, field slope and drainage, irrigation system type and management, fertilizer and manuring practices, and other soil and water management practice. However, the most critical factor in predicting, managing, and reducing salt-affected soils is the quality of irrigation water being used. Besides affecting crop yield and soil physical conditions, irrigation water quality can affect fertility needs, irrigation system performance and longevity, and how the water can be applied. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity.

Electrical conductivity (EC) is the most convenient way of measuring water salinity. EC is determined as the reciprocal of the specific resistance (ohms.m) of the water sample corrected to a standard temperature, usually 25°C.The basic unit of EC in SI units is Siemens m^{-1} (previously mhos m^{-1}). Formerly water salinities were expressed in micro mhos cm^{-1}.

Some useful conversions are:

1 mS m^{-1} = 0.01 m mho cm^{-1} =10 mμho cm^{-1}

e.g. a water may have EC = 2000 μmho cm^{-1} = 2 mmho cm^{-1} = 200 mS m^{-1}

Frequently EC is multiplied by a factor to obtain total soluble salts (mass/volume) as an expression of salinity. There is however no unique factor that can be applied and the factor will vary with composition and concentration. Factors found for W.A. waters vary between 5.0 and 8.5 (EC in mS m^{-1}). Generally it is more convenient to use electrical conductivity as the measure of salt content as criteria are usually published in this form. Other terms that laboratories and literature sources use to report salinity hazard are: salts, salinity, electrical conductivity (EC_w), or total dissolved solids (TDS). These terms are all comparable and all quantify the amount of dissolved "salts" (or ions, charged particles) in a water sample. However, TDS is a direct measurement of dissolved ions and EC is an indirect measurement of ions by an electrode. Although people frequently confuse the term "salinity" with common table salt or sodium chloride (NaCl), EC measures salinity from all the ions dissolved in a sample. This includes negatively charged ions (e.g., Cl^-, NO^-_3) and positively charged ions (e.g., Ca^{++}, Na^+). Another common source of confusion is the variety of unit systems used with EC_w. The preferred unit is deciSiemens per meter (dS/m), however millimhos per centimeter (mmho/cm) and micromhos per centimeter (μmho/cm) are still frequently used. Conversions to help you change between unit systems are provided in Table 2.

Component	To Convert	Multiply By	To Obtain
Water nutrient or TDS	mg/L	1.0	ppm
Water salinity hazard	1 dS/m	1.0	1 mmho/cm
Water salinity hazard	1 mmho/cm	1,000	1 μmho/cm
Water salinity hazard	EC_w (dS/m) for EC <5 dS/m	640	TDS (mg/L)
Water salinity hazard	EC_w (dS/m) for EC >5 dS/m	800	TDS (mg/L)
Water NO_3N, SO_4-S,B applied	Ppm	0.23	lb per acre inch of water
Irrigation water	acre inch	27,150	gallons of water

Table 2. Conversion factors for irrigation water quality laboratory reports. Source: Bauder *et al.*, 2011

Definitions

Abbrev.	Meaning
mg/L	milligrams per liter
meq/L	milliequivalents per liter
Ppm	parts per million
dS/m	deciSiemens per meter
μS/cm	microSiemens per centimeter
mmho/cm	millimhos per centimeter
TDS	total dissolved solids

2.2 Sodium hazard/SAR

Although plant growth is primarily limited by the salinity (EC_w) level of the irrigation water, the application of water with a sodium imbalance can further reduce yield under certain soil texture conditions. Reductions in water infiltration can occur when irrigation water contains high sodium relative to the calcium and magnesium contents. This condition is termed "sodicity," and results from excessive accumulation of sodium in soil. Sodic water is not the same as saline water. Sodicity causes swelling and dispersion of soil clays, surface crusting and pore plugging. This degraded soil structure condition in turn obstructs infiltration and may increase runoff. Sodicity therefore, causes a decrease in the downward movement of water into and through the soil, and actively growing plants roots may not get adequate water, despite pooling of water on the soil surface after irrigation. The most common measure to assess sodicity in water and soil is called the Sodium Adsorption Ratio (SAR). The SAR defines sodicity in terms of the relative concentration of sodium (Na) compared to the sum of calcium (Ca) and magnesium (Mg) ions in a sample. The SAR assesses the potential for infiltration problems due to a sodium imbalance in irrigation water. The SAR is used to estimate the sodicity hazard of the water, where:

$$SAR = \frac{Na}{0.5\,(ca + mg)}$$ and all concentrations are in meq/L

SAR is a measure of the tendency of the irrigation water to cause the replacement of calcium (Ca) ions attached to the soil clay minerals with sodium ions (Na). Sodium clays have poor structure and develop permeability problems. The Residual sodium carbonate (RSC) is the measure in milli equivalents per litre (meq/L) of the excess of carbonates (CO_3) and bicarbonates (HCO_3) over magnesium (Mg) and calcium (Ca). With high RSC (>1.25) there is a tendency for Ca and Mg to precipitate in the soil, thus increasing the proportion of Na and increasing the SAR of the soil solution.

Potential for Water Infiltration Problem		
Irrigation water SAR	Unlikely	Likely
	EC_w* (dS/m)	
0-3	>0.7	<0.2
3-6	>1.2	<0.4
6-12	>1.9	<0.5.
12-20	>2.9	<1.0
20-40	>5.0	<3.0

*Modified from Ayers and Westcot. 1994. Water Quality for Agriculture, Irrigation and Drainage Paper 29, rev. 1, Food and Agriculture Organization of the United Nations, Rome.

Table 3. Guidelines for assessment of sodium hazard of irrigation water based on SAR and EC_w[2].

2.3 pH and alkalinity

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH for irrigation water ranges from 6.5 to 8.4. High pH's above 8.5 are often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentrations, known as alkalinity. Calcium and magnesium ions become insoluble due to high carbonates and bicarbonates thereby leaving sodium as the dominant ion in solution. As also described in the sodium hazard section, this alkaline water could intensify the impact of high SAR water on sodic soil conditions. The main use of pH in a water analysis is for detecting an abnormal water. The normal pH range for irrigation water is from 6.5 to 8.4. An abnormal value is a warning that the water needs further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion. Low salinity water (ECw < 0.2 dS/m) sometimes has a pH outside the normal range since it has a very low buffering capacity. This should not cause undue alarm other than to alert the user to a possible imbalance of ions and the need to establish the reason for the adverse pH through full laboratory analysis. Such water normally causes few problems for soils or crops but is very corrosive and may rapidly corrode pipelines, sprinklers and control equipment. Any change in the soil pH caused by the water will take place slowly since the soil is strongly buffered and resists change. An adverse pH may need to be corrected, if possible, by the introduction of an amendment into the water, but this will only be practical in a few instances. It may be easier to correct the soil pH problem that may develop rather than try to treat the water.

Lime is commonly applied to the soil to correct a low pH and sulphur or other acid material may be used to correct a high pH. Gypsum has little or no effect in controlling an acid soil problem apart from supplying a nutritional source of calcium, but it is effective in reducing a high soil pH (pH greater than 8.5) caused by high exchangeable sodium. The greatest direct hazard of an abnormal pH in water is the impact on irrigation equipment. Equipment will need to be chosen carefully for unusual water.

2.4 Chloride

Chloride is a common ion in most of the irrigation waters. Although chloride is essential to plants in very low amounts however, it can cause toxicity to sensitive crops at high concentrations. Like sodium, high chloride concentrations cause more problems. The degree of damage depends on the uptake and the crop sensitivity. The permanent, perennial-type crops (tree crops) are more sensitive. Damage often occurs at relatively low ion concentrations for sensitive crops. It is usually first evidenced as marginal leaf burn and interveinal chlorosis. If the accumulation is great enough, reduced yields result. The more tolerant annual crops are not sensitive at low concentrations but almost all crops will be damaged or killed if concentrations are amply high.

2.5 Boron

Boron, unlike sodium, is an essential element for plant growth (Chloride is also essential but in such small quantities that it is frequently classed non-essential.) Boron is needed in relatively small amounts, however, if present in amounts appreciably greater than needed, it becomes toxic. For some crops, if 0.2 mg/l boron in water is essential, 1 to 2 mg/l may become toxic. Surface water rarely contains enough boron to be toxic but well water or springs occasionally may contain toxic amounts, especially near geothermal areas and earthquake faults. Boron problems originating from the water are probably more frequent than those originating in the soil. Boron toxicity can affect nearly all crops but, like salinity, there is a wide range of tolerance among crops. Boron toxicity symptoms normally show first on older leaves as a yellowing, spotting, or drying of leaf tissue at the tips and edges. Drying and chlorosis often progress towards the centre between the veins (interveinal) as more and more boron accumulates with time. On seriously affected trees, such as almonds and other tree crops which do not show typical leaf symptoms, a gum or exudate on limbs or trunk is often noticeable. Most crop toxicity symptoms occur after boron concentrations in leaf blades exceed 250–300 mg/kg (dry weight) but not all sensitive crops accumulate boron in leaf blades. For example, stone fruits (peaches, plums, almonds, etc.), and pome fruits (apples, pears and others) are easily damaged by boron but they do not accumulate sufficient boron in the leaf tissue for leaf analysis to be a reliable diagnostic test. With these crops, boron excess must be confirmed from soil and water analyses, tree symptoms and growth characteristics.

A wide range of crops were tested for boron tolerance by using sand-culture techniques (Eaton 1944). Previous boron tolerance tables in general use have been based for the most part on these data. These tables reflected boron tolerance at which toxicity symptoms were first observed and, depending on crop, covered one to three seasons of irrigation. The original data from these early experiments, plus data from many other sources, have recently been reviewed (Maas 1984). Table 4 presents this recent revision of the data. It is not based on plant symptoms, but upon a significant loss in yield to be expected if the indicated boron value is exceeded.

Sensitive		Moderately Sensitive	Moderately Tolerant	Tolerant
0.5-0.75	0.76-1.0	1.1-2.0	2.1-4.0	4.1-6.0
Peach	Wheat	Carrot	Lettuce	Alfalfa
Onion	Barley	Potato	Cabbage	Sugar beet
	Sunflower	Cucumber	Corn	Tomato
	Dry Bean		Oats	

Source: Mass (1984) Salt tolerance of plants. CRC Handbook of Plant Science in Agriculture. B.R. Cristie (ed.). CRC Press Inc.

Table 4. Boron sensitivity of selected Colorado plants (B concentration, mg/ L*)

2.6 Sulfate

The sulfate ion is a major contributor to salinity in many of the irrigation waters. As with boron, sulfate in irrigation water has fertility benefits, and most often irrigation water has enough sulfate for maximum production for most crops. Exceptions are sandy fields with <1 percent organic matter and <10 ppm SO_4-S in irrigation water.

2.7 Nitrate

Nitrogen in irrigation water (N) is largely a fertility issue, and nitrate-nitrogen (NO_3-N) can be a significant N source as it is found in most of the wastewaters throughout the world. The nitrate ion often occurs at higher concentrations than ammonium in irrigation water. Nitrogen is a plant nutrient and stimulates crop growth. Natural soil nitrogen or added fertilizers are the usual sources, but nitrogen in the irrigation water has much the same effect as soil-applied fertilizer nitrogen and an excess will cause problems, just as too much fertilizer would. If excessive quantities are present or applied, production of several commonly grown crops may get disturbed because of over-stimulation of growth, delayed maturity or poor quality. However, these problems can usually be overcome by good fertilizer and irrigation management. The sensitivity of crops varies with the growth stage. High nitrogen levels may be beneficial during early growth stages but may cause yield losses during the later flowering and fruiting stages (Tak et al., 2010). High nitrogen water can be used as a fertilizer early in the season. However, as the nitrogen needs of the crop diminish later in the growing season, the nitrogen applied to the crop must be substantially reduced. For crops irrigated with water containing nitrogen, the rates of nitrogen fertilizer supplied to the crop should be reduced by an amount very nearly equal to that available from the water supply. Regardless of the crop, nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 ppm NO_3-N (45 ppm NO_3^-).

2.8 Trace elements and heavy metals

A number of elements are normally present in relatively low concentrations, usually less than a few mg/l, in conventional irrigation waters and are called trace elements. They are not normally included in routine analysis of regular irrigation water, but attention should be paid to them when using sewage effluents, particularly if contamination with industrial wastewater discharges is suspected. These include Aluminium (Al), Beryllium (Be), Cobalt (Co), Fluoride (F), Iron (Fe), Lithium (Li), Manganese (Mn), Molybdenum (Mo), Selenium

(Se), Tin (Sn), Titanium (Ti), Tungsten (W) and Vanadium (V). Heavy metals are a special group of trace elements which have been shown to create definite health hazards when taken up by plants. Under this group are included, Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg) and Zinc (Zn). These are called heavy metals because in their metallic form, their densities are greater than 4g/cc. Table 6 gives the insight on the recommended maximum concentration of trace elements in irrigation water.

2.9 Guidelines

Water quality criteria can never be absolute because soils, management and drainage can influence water suitability. There is, for example a ten—fold range in the salt—tolerance of plants which gives wide scope for utilizing water of different quality. Table 5 (FAO 1985) gives broad guidelines that have been developed for the preliminary evaluation of irrigation water quality. Where a water quality parameter is in the range of increasing problems more detailed investigation is required. For instance, in the range of increasing salinity problems (0.7 to 3.0 dS m^{-1}) more concern is required in the selection of plant species and precautions are needed to minimize salt injury. Where limitations are given the application of appropriate management methods may mean that the waters are still viable. The table thus avoids rigid classification methods which can at times be misleading. They emphasize the long-term influence of water quality on crop production, soil conditions and farm management, and are presented in the same format as in the 1976 edition but are updated to include recent research results. This format is similar to that of the 1974 University of California Committee of Consultant's Water Quality Guidelines which were prepared in cooperation with staff of the United States Salinity Laboratory. The guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. A modified set of alternative guidelines can be prepared if actual conditions of use differ greatly from those assumed. Ordinarily, no soil or cropping problems are experienced or recognized when using water with values less than those shown for ‘no restriction on use’. With restrictions in the slight to moderate range, gradually increasing care in selection of crop and management alternatives is required if full yield potential is to be achieved. On the other hand, if water is used which equals or exceeds the values shown for severe restrictions, the water user should experience soil and cropping problems or reduced yields, but even with cropping management designed especially to cope with poor quality water, a high level of management skill is essential for acceptable production. If water quality values are found which approach or exceed those given for the severe restriction category, it is recommended that before initiating the use of the water in a large project, a series of pilot farming studies be conducted to determine the economics of the farming and cropping techniques that need to be implemented. Table 5 is a management tool. As with many such interpretative tools in agriculture, it is developed to help users such as water agencies, project planners, agriculturalists, scientists and trained field people to understand better the effect of water quality on soil conditions and crop production. With this understanding, the user should be able to adjust management to utilize poor quality water better. However, the user of Table 5 must guard against drawing unwarranted conclusions based only on the laboratory results and the guideline interpretations as these must be related to field conditions and must be checked, confirmed and tested by field trials or experience. The guidelines are a first step in pointing out the quality limitations of a water supply, but this alone is not enough; methods to overcome or adapt to them are also needed. The guidelines do not evaluate the effect of unusual or special water constituents sometimes found in wastewater, such as pesticides and organics. However, suggested limits of trace element concentrations or normal irrigation water are given in Table 6. The World Health Organization (WHO) or a local health agency should be consulted for more specific information. Laboratory determinations and calculations needed to use the guidelines are given in Table 7 along with the symbols used. Analytical procedures for the laboratory determinations are given in several publications: USDA Handbook 60 (Richards 1954), Rhoades and Clark 1978, FAO Soils Bulletin 10 (Dewis and Freitas 1970), and Standard Methods for Examination of Waters and Wastewaters (APHA 1980). The method most appropriate for the available equipment, budget and number of samples should be used. Analytical accuracy within ±5 percent is considered adequate.

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
EC_W	ds/m	<0.7	0.7-3.0	>3.0
Or				
TDS	mg/l	<450	450-2000`	>2000
Infiltration				
SAR and EC_W				
0-3		>0.7	0.7-0.2	<0.2
3-6		>1.2	1.2-0.3	<0.3
6-12		>1.9	1.9-0.5	<0.5.
12-20		>2.9	2.9-1.3	<1.3
20-40		>5.0	5.0-2.9	<3.0
Specific ion toxicity				
Sodium (Na)				
Surface irrigation	SAR	<3.0	3-9	>9
Sprinkler irrigation	me/l	<3.0	>3	
Chloride				
Surface irrigation	me/l	<4.0	4-10	>10
Sprinkler irrigation	m^3/l	<3.0	>4.0	
Boron (B)	mg/l	<0.7	0.7-3.0	>3.0
Nitrogen (NO_3-N)	mg/l	<5.0	5.0-30	>30
Bicarbonate (HCO_3)	me/l	<1.5	1.5-8.5	>8.5
pH	Normal range 6.5-8.0			

Table 5. Guidelines for determination of water quality for irrigation Source FAO, 1985

Element	Recommended Maximum Concentration* (mg/l)	Remarks
Al(aluminium)	5.0	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)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.10	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)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe (iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
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.
Mn (manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
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)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd (lead)	5.0	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.
Ti (titanium)	----	Effectively excluded by plants; specific tolerance unknown.
V (vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

*The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10000 m3 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. Source: FAO, 1985

Table 6. Recommended maximum concentrations of trace elements in irrigation water

Parameters	Symbol	Units
Physical		
Total dissolved solids	TDS	mg/l
Electrical conductivity	Ecw	dS/m1
Temperature	T	°C
Colour/Turbidity		NTU/JTU2
Hardness		mg equiv. CaCO3/l
Chemical		
Acidity/Basicity	pH	
Type and concentration of anions and cations:		
Calcium	Ca^{++}	me/l[3]
Magnesium	Mg^{++}	me/l
Sodium	Na^{+}	me/l
Carbonate	CO_3^{--}	me/l
Bicarbonate	HCO_3^{-}	me/l
Chloride	Cl^{-}	me/l
Sulphate	SO_4^{-}	me/l
Sodium Absorption Ratio	SAR	
Boron	B	mg/l[4]
Nitrate-Nitrogen	NO_3-N	mg/l
Phosphate Phosphorus	PO_4-P	mg/l
Potassium	K	mg/l
Trace metals		mg/l
Heavy metals		mg/l

Table 7. Parameters used in the evaluation of agricultural water quality Source: Kandiah (1990)

3. Health guidelines

Guidelines for the safe use of wastewater in agriculture need to maximize public health benefits while allowing for the beneficial use of scarce resources. Achieving this balance in the variety of situations that occur worldwide (especially in settings where there may be no wastewater treatment) can be difficult. Guidelines are needed to be adaptable to the local social, economic, and environmental conditions and should be co-implemented with such other health interventions as hygiene promotion, provision of adequate drinking water and sanitation, and other healthcare measures. The *Hyderabad Declaration on Wastewater Use in Agriculture* recognises these principles and recommends a holistic approach to the management of wastewater use in agriculture. Following a major expert meeting in Stockholm Sweden in 1999, the International Water Association (IWA) on behalf of the

World Health Organization (WHO) published *"Water Quality: Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-related Infectious Disease"*. This publication outlines a harmonized framework for the development of guidelines and standards for water-related microbiological hazards (Bartram *et al.*, 2001; Prüss and Havelaar, 2001). The suggested framework involves the assessment of health risks prior to setting health targets; defining basic control approaches, and evaluating the impact of these combined approaches on public health status (Fig. 1). The framework is flexible and allows countries to adjust the guidelines to local circumstances and compare the associated health risks with risks that may result from microbial exposures through drinking water or recreational/occupational water contact (Bartram *et al.*, 2001). It is important that health risks from the use of wastewater in agriculture be put into the context of the overall level of gastrointestinal disease within a given population. The regulation of water quality for irrigation is of international importance because trade in agricultural products across regions is growing and products grown with contaminated water may cause health effects at both the local and transboundary levels. Exports of contaminated fresh produce from different geographical regions can facilitate the spread of both known pathogens and strains with new virulence characteristics into areas where such pathogens are not normally found.

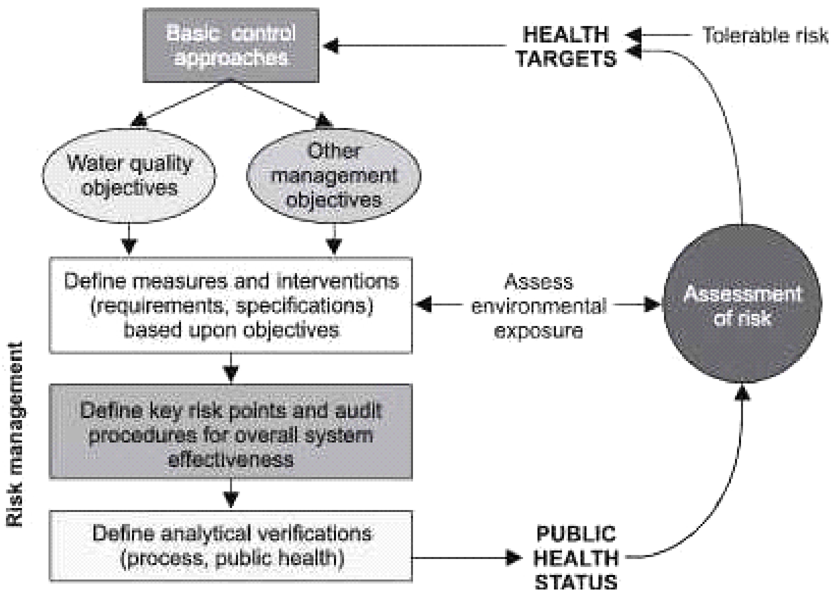

Fig. 1. Stockholm Framework for assessment of risk for water-related microbiological hazards (adapted from Bartram et al., 2001).

Effective guidelines for health protection should be: feasible to implement; adaptable to local social, economic, and environmental factors; and include the following elements:

- Evidence-based health risk assessment
- Guidance for managing risk (including options other than wastewater treatment)
- Strategies for guideline implementation (including progressive implementation where necessary).

Worldwide many different microbial standards for wastewater use in agriculture have been developed. Most guidelines lay heavy emphasis on microbial standards, but it should be recognized that other strategies for managing health risks may also be effective.

4. Conclusion

Water quality criteria for the use in agriculture should not be used without considering various interactive factors. Guidelines established by Ayres and Westcott (1976) takes a better approach to water quality evaluation. Improving the overall levels of agronomic and cultural management to improve water use efficiency can offset yield losses due to poor quality water and improve or maintain profitability. Plants respond to osmotic and ion toxicity effects with a gradually declining yield as water quality deteriorates. This enables the farmer either to accept this loss or to determine whether the marginal return to the cost incurred in avoiding salinity or toxicity problems is worthwhile. Because of the wide range of species tolerance to salinity and toxicity the type of crop being grown has a large bearing on these decisions. Occasional irrigations with poor quality water are often more beneficial than no water at all especially in a Mediterranean environment where salt build—up in the soil is prevented by heavy winter rainfall. Developing realistic guidelines for using wastewater in agriculture also involves the establishment of appropriate health-based targets prior to defining appropriate risk-management strategies. Establishing appropriate health-based targets primarily involves an assessment of the risks associated with wastewater use in agriculture, using evidence from available studies of epidemiological and microbiological risks, and risk-assessment studies. Considerations of what is an acceptable or tolerable risk are then necessary; these may involve the use of internationally derived estimates of tolerable risk, but these need to be put into the context of actual disease rates in a population related to all the exposures that lead to that disease, including other water- and sanitation-related exposures together with food-related exposure. Positive health impacts resulting from increased food security, improved nutrition, and additional household income should also be considered. Individual countries may therefore set different health targets, based on their own contexts. Strategies for managing health risks to achieve the health targets include wastewater treatment to achieve appropriate microbiological quality guidelines, crop restriction, waste application methods, control of human exposure, chemotherapy, and vaccination.

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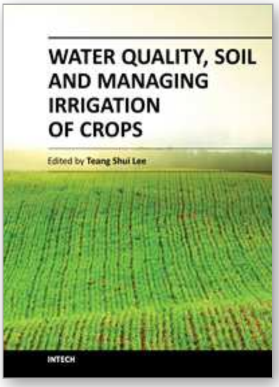

Water Quality, Soil and Managing Irrigation of Crops

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The book entitled Water Quality, Soil and Managing Irrigation of Crops comprises three sections, specifically: Reuse Water Quality, Soil and Pollution which comprises five technical chapters, Managing Irrigation of Crops with four, and Examples of Irrigation Systems three technical chapters, all presented by the respective authors in their own fields of expertise. This text should be of interest to those who are interested in the safe reuse of water for irrigation purposes in terms of effluent quality and quality of urban drainage basins, as well as to those who are involved with research into the problems of soils in relation to pollution and health, infiltration and effects of irrigation and managing irrigation systems including basin type of irrigation, as well as the subsurface method of irrigation. The many examples are indeed a semblance of real world irrigation practices of general interest to practitioners, more so when the venues of these projects illustrated cover a fair range of climate environments.