The chemical blueprint: Deciphering Salinity, Sodicity, Toxicity Hazards in Irrigation water

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Abstract: Irrigation water quality refers to its suitability and sustainability for use in agricultural crop fields. The influence of water quality on the soil and plant growth is related to the chemical and physical properties of the soil, the salt tolerance of the crop growth, the climatic regime of the area and the method, frequency and the amount of irrigation water applied. Hence to formulate a comprehensive irrigation water classification scheme for agricultural crops different irrigation water quality parameters like electrical conductivity, total salt concentration, sodium hazard, boron toxicity, residual sodium carbonate, etc are to be considered conscientiously.

Key words: Irrigation water, salt concentration, sodium hazard, boron toxicity

Introduction

Irrigated agriculture is playing a major role in enhancing food and livelihood security of a country. Supply of fresh water which is an important input for the sustainable and economic development of agriculture are not enough to meet the requirement of all sectors of economy. Reduced water availability to agriculture from the present share of 85% of country's water resources to about 70-75% by 2020AD would affect the capacity of the country to meet the food production target, unless supplies are augmented from unconventional sources. For future agriculture there are no alternatives but to rely on non conventional sources for partial alleviation of the forecasted water scarcity. Among these sources extraction of marginal quality ground water and the waste water generated from urban and industrial activities have the potential to augment the water supplies. Many associated soil, plant and environmental problems come up when these sources of water are directly used for irrigation. For addressing these problems and to get more benefit from these sources of water, the first step is to understand how an irrigation water source affects the soil plant system. Therefore knowledge of irrigation water quality is critical to develop appropriate site and crop specific comprehensive short term and long term management programs.

Suitability of irrigation water

The suitability of irrigation water depends upon several factors such as water quality, soil type, plant characteristics, irrigation method, drainage, climate and local conditions. The integrated effect of these factors on the suitability of irrigation water (SI) can be expressed by the relationship given below;

$$SI = QSPCD$$

Where;

Q = quality of irrigation water, that is total salt concentration, relative proportion of cations

S = Soil type, texture, structure, permeability, fertility, calcium carbonate content, type of clay minerals, initial level of salinity and alkalinity before irrigation

P = Salt tolerance characteristics of the crop, its variety and growth stage

C = Climate that is, total rainfall, its distribution, and evaporation characteristics

D = Drainage conditions, depth of water table, nature of soil profile, presence of hard pan or lime concretion and management practices

These factors act interactively such that a single suitable criterion is hard to be adopted for widely varying conditions. However Bureau of Indian Standards (BIS) has developed some general broad guidelines (IS: 11624-1986) for assessment of water quality which were reaffirmed in 2001 and 2009.

Water Quality Evaluation

Conceptually water quality refers to its suitability for a specific use and the criteria for judging water quality for different purposes are different. Specific uses have different quality needs and among all sectors of water use, agriculture is most sensitive to water scarcity and water quality.

The objective of water quality evaluation is to assess its suitability for irrigation and assist to cope with potential water quality problems that might reduce production through management. Basing on the experiences and measured responses certain parameters have emerged as indicators of irrigation water quality. These indicators are then organized into guidelines related to suitability for use. Numerous such guidelines are available covering many types of use. Figure 1 is a flow diagram suggesting a concept for assessing water quality. Plant tolerance allows a wide range of options as to suitable crops and this feeds back into management aspects which determine whether these crops are profitable or whether the yield losses due to salinity or toxicity are acceptable (Maas and Hoffman, 1977). Under soil factors where quality is marginal, there is a possibility of adding ameliorants to the soil or changing to another soil type to avoid problem.

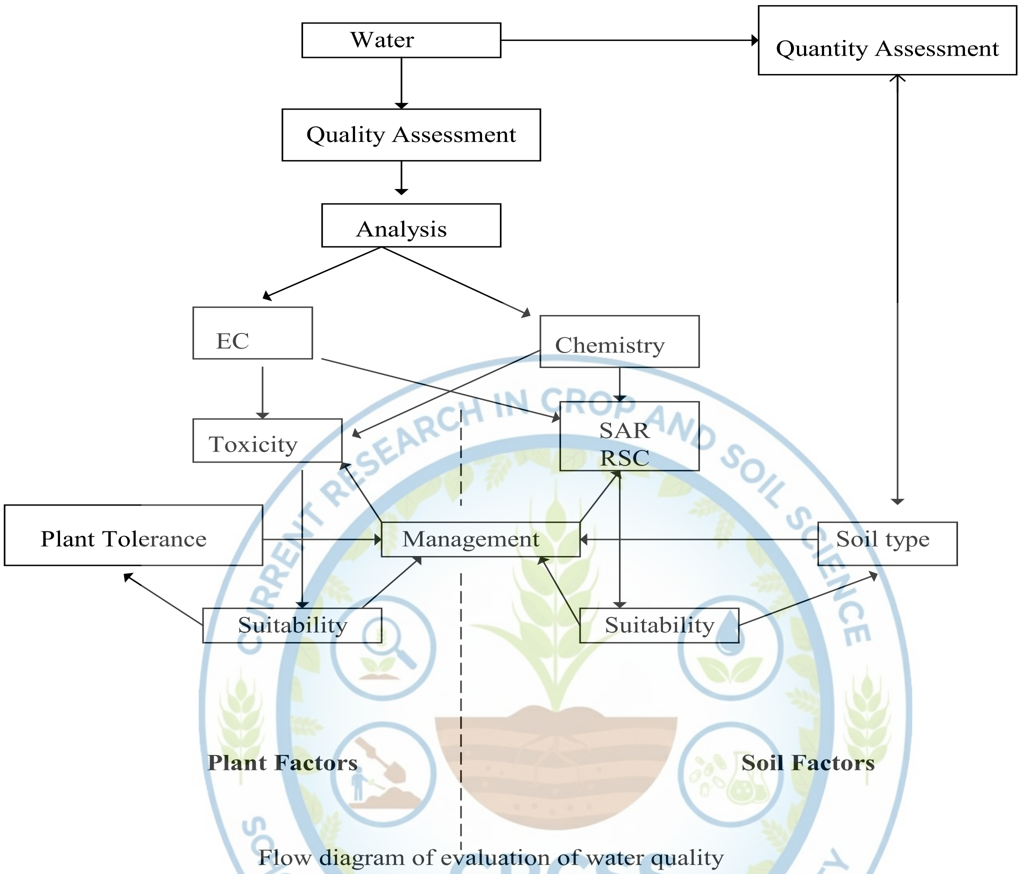

Fig 1: Flow diagram of evaluation of water quality

Water Quality Guidelines

There have been a number of different water quality guidelines related to irrigated agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in field conditions. Water used for irrigation varies greatly in quality depending upon type and quality of dissolved salt. The suitability of water for irrigation is determined not only by the total amount of salt but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases and special management practices are required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long term use.

The problem that results vary in kind and degree that are modified by soil, climate and crop as well as by the skill and knowledge of the water use. As a result there is no set limit on water quality rather its suitability for use is determined by the conditions of use which affects accumulation of the water constituents and which may restricts crop yield. The soil problems that are most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity of ions and a group of other miscellaneous problems.

(i) ***Salinity***: It is related mainly to osmotic potential and its effect on crop growth. It is determined by salt concentration rather than specific constituents. The guideline indicates that it is necessary to consult detailed tolerance tables to determine plants which would not suffer unacceptable yield loss (Ayres and Westcott, 1976; Shainberg and Oster, 1978).

(ii) ***Sodicity***: The sodic (sodium) hazard is related to the detrimental effect of the exchangeable sodium percent (ESP) on soil structure and the direct toxic effect on sodium sensitive plants.

(iii) ***Toxicity***: This is the specification effects of solutes (excluding sodium) of a nutritional nature, e.g. boron, lithium, chlorine and certain heavy metals.

1. Salinity Problems

A salinity problem due to water quality occurs if salts from applied irrigation water accumulate in crop root zone beyond certain limits and yields are affected with shallow water tables, a salinity problem may also exist due to upward movement of salts from ground water as the water evaporates from the soil or used by the crop.

The total concentration of soluble salts in irrigation water can be adequately expressed in term of electrical conductivity (EC). The basic unit for EC is deci Siemen per meter (dS m^{-1}). The electrical conductivity values of irrigation water can also be converted into other reporting units (James et al., 1982) such as;

(i) EC (dS m^{-1}) × 640 = Total salt concentration, mg L^{-1} or ppm .... (1)

(ii) EC (dS m^{-1}) × 0.36 = Osmotic pressure, bar .... (2)

(iii) EC (dS m^{-1}) ×10 = Total cation or anion concentration, meq L^{-1} .... (3)

Irrigation water classification for salinity hazard used as a guidelines as proposed by Richards (1954) is presented in Table 1. For assessing the suitability of particular irrigation water in a specified crop rotation, the salinity limits given in Table 2 may be adjusted/corrected for rainfall in the region.

Table2: USDA classification of irrigation water salinity

Salinity class and description		EC range(dSm^{-1})	Equivalent salt concentration (mg L^{-1})
C1	Low salinity water-good for most soils and crops	< 0.25	< 200
C2	Medium salinity water-some leaching for sensitive crops	0.25-0.75	200-500
C3	High salinity water tolerant crops and leaching required	0.75-2.25	500-1500
C4	Very high salinity water only for permeable soils and tolerant crops	> 2.25	> 1500

Source: (Richards, 1954)

Water quality rating for salinity hazard as proposed by workers in India is reported in Table 2. With appropriate management practices the hazards due to use of poor quality waters can be minimized for sustained production of crops in a given situation. Limits of salinity in irrigation water for achieving specified yield levels (relative) in various crops under different climatic and soil conditions have been given in Table 3. Hammed *et al.* (1966) stated that waters having EC value less than 1.5 dS m^{-1} are safe for irrigation, those having 1.5 to 3.0 dSm^{-1} are marginal and waters having EC values more than 3.0 dSm^{-1} are unsafe.

Table 3*:* Guidelines for using poor quality irrigation Water (Recommendation of AICRP – Saline Water, CSSRI, HAU and PAU, 1990)

Soil texture (% clay)	Crop tolerance	Upper limit of EC_{iw} (dS m^{-1}) in rainfall region (mm)		
		< 350	350-550	550-750
Fine (> 30)	Sensitive (S)	1.0	1.0	1.5
	Semi-tolerant (ST)	1.5	2.0	3.0
	Tolerant (T)	2.0	3.0	4.5
Moderately fine (20-30)	S	1.5	2.5	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately coarse (10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (< 10)	S	--	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

Selection of Crop(s)

Amongst the general guidelines for selecting crops and cropping sequences, tolerant or semi tolerant crops having low water requirement such as barley, wheat, mustard, pearl millet and sorghum (promising varieties are given in table 4) should be grown while crops with high water requirement such as rice, sugarcane and berseem should be avoided. In low rainfall area (having annual rainfall < 400 mm) if good quality canal water is unavailable, it is desirable to keep the fields fallow during kharif season. During rabi, only tolerant and semi tolerant crops like barley, wheat and mustard should be grown. In area having high rainfall (having annual rainfall > 400 mm) sorghum – wheat, guar- wheat, pearl millet- wheat and cotton- wheat rotations can be practiced, provided sowing of kharif crops is completed with rainwater or good quality canal water. Not more than 2 or 3 irrigations should be applied with sodic water during the kharif season. Sodic water should not be used to grow summer crops (Gupta, 2010).

Table 4: Promising varieties for alkali tolerance from CSSRI and other places

Crops	pH/ ESP	Varieties/ Genotype
Rice	9.4 – 10.2 9.4 – 9.8	CSR 10 CSR 13, CSR 23, CSR 27, CSR 36, CSR 30
Wheat	9.2 – 9.3	KRL 1-9, KRL 19, KRL 99, WH 157, Raj. 3077
Mustard	12 – 38 (ESP)	Pusa bold, Varuna, Kranti, CSR 52, CSR 54, CS 56
Chickpea	Upto 9.3	Karnal Chana 1
Barley	Upto9.3	CSB 1, CSB 2, CSB 3, DL 200, DL 348, Ratan, BH 97, AZAD
Dhaincha		CSD 137, CSD 123

Source: Gupta, 2010

Ideally it would be inferred that EC of irrigation water should be as low as possible, but the water which is completely free of soluble salts is never the best for irrigation. The water having EC less than 0.2 dSm-1 have no fertility value and are well known to create permeability problem in the preferably less than1.5 dS m^{-1} so that irrigated soil dose not even become saline and there is full choice to grow the crops (Gupta and Gupta, 2003).

2. Sodicity problems

Among the soluble constituents of irrigation water, sodium (Na) is considered to be most hazardous. Water which might be suitable under salinity classification may not be suitable, if sodium predominates. The effect of sodium is two fold. It affects the permeability of soil causing by swelling and dispersion of clay particles and clogging the soil pores and it may cause injury to crops specifically sensitive to sodium such as fruit crops. Irrigation water containing large amount of sodium is of concern due to absorbed sodium by plant roots which is transported to leaves where it can accumulated and cause injury (Begum and Rasul, 2009). The sodium adsorption ratio (SAR) has been proposed as a useful measure of sodium hazards of irrigation water (Richards, 1954). This parameter is defined by the relationship as;

$$SAR_{iw} = \frac{(Na^{+})}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}} \qquad \text{------------------------------------ (4)}$$

where, the ionic concentrations are expressed in miliequivalents per litre (meL^{-1}).

Based on SAR values of irrigation water, its suitability can be evaluated with the help of rating given in the Table 5. In practice many irrigation water contains sufficient quantities of sulphate and bicarbonate ions to produce precipitation of calcium sulphate and calcium carbonate that remove calcium from solution and hence markedly increase sodium hazards. SAR under this situation may not give the correct sodium hazard since it is the SAR of soil water (SARsw) value rather than the SAR of irrigation water (SARiw) value that affect the ESP of the soil and an eventually the soil permeability. Hence a new index called adjusted SAR (SAR_{adj}) is suggested by Rhoades (1969 a) and is calculated by using the following formula (Ayers and Westcot, 1976).

$$SAR_{adj} = SAR_{iw}(1 + (8.4 - pHc) \qquad \text{-- (5)}$$

The term $(8.4 - pHc)$ reflects the tendency of the applied water to precipitate or dissolve $CaCO_3$. The pHc term is defined as the theoretical pH of irrigation water with a given calcium, magnesium and HCO_3^- + CO_3^- concentration, which is in equilibrium with solid $CaCO_3$. When $(8.4 - pHc) > 0$ calcium carbonate precipitates in the soil when the water is applied and when $(8.4 - pHc) < 0$, the irrigation water dissolves calcium carbonate if present in the soil. The term pHc is calculated from the equation;

$$pHc = (pk_2' + pk_c') + p(HCO_3^- + CO_3^{2-})/2 + p(Ca^{2+} + Mg^{2+}) \qquad \text{------------------ (6)}$$

Where,

$(pk_2' - pk_c')$ is obtained from the sum of the concentration of $Ca^{2+} + Mg^{2+} + Na^{+}$ in meq L^{-1} as given in Table 6. pk_2' and pk_c' are the negative logarithms of the second dissociation constant of H_2CO_3 and the solubility-product constant of $CaCO_3$, respectively.

$p(Ca^{2+} + Mg^{2+})/2$ = negative log of concentration of calcium and magnesium in eq L^{-1}

$p(HCO_3^- + CO_3^{2-})$ = negative log of $HCO_3^- + CO_3^{2-}$ concentration in eq L^{-1}

Table 6: values of $pk_2' + pk_c'$ for respective salt concentration in irrigation water

Sum of salt concentration (meq L^{-1})	$pk_2' + pk_c'$
0.05-0.49	2.0
0.50-1.50	2.1
1.51-6.0	2.2
5.10-20.0	2.3
20.10-30.0	2.4
30.10-80.0	2.5

Calculation of SAR_{adj}

Given;

Ca = 2.23 meq L^{-1}
Mg = 1.44 meq L^{-1}
Na = 7.73 meq L^{-1}

Sum = 11.79 meq L^{-1}

CO_3 = 0.42 meq L^{-1}
HCO_3 = 3.66 meq L^{-1}

Sum = 4.08 meq L^{-1}

From the above table and using the equation for pHc.

$(pk_2' + pk_c')$ = 2.3 (From table above)
$p(Ca^{2+} + Mg^{2+})/2$ = 2.7 (calculated)
$p(HCO_3^- + CO_3^-)$ = 2.4 (calculated)

Total = 7.4

Substituting the value of pHc, the SAR_{adj} will be;

$$SAR_{adj} = \frac{7.73\ (1+8.4-7.4)}{\sqrt{3.67/2}} = 11.3$$

With the help of values of SAR_{adj} quality of irrigation water for sodicity hazards can be evaluated using the guidelines given in Table 7.

In India, Gupta (1979) reported the following irrigation water suitability classification based on values of SAR_{adj}.

Table 7: Irrigation water and its suitability based on SAR_{adj} values

SAR_{adj}	Classification	Rating with suitability
< 10	S_1	Low: Suitable to black and alluvial soils, clay > 30% and fair to moderate drainage
10-20	S_2	Medium : Suitable to soils with clay 20-30 % and good drainage
20-30	S_3	High : suitable to soils with clay 10-20 % and good drainage
30-40	S_4	Very high : suitable to only light textured soils, clay < 10% and excellent drainage
> 40	S_5	unsuitable

However, Oster and Rhoades (1977), Oster and Schroer (1979) and Suarez (1981) carefully evaluated the adj. SAR procedure and concluded that it over predicts the sodium hazard. They suggested that, if used, the value obtained by that method should be further adjusted by a 0.5 factor to evaluate more correctly the effects of HCO_3 on calcium precipitation (adj. SAR × 0.5). Soon after irrigation, dissolution or precipitation may occur, changing the supply of calcium and establishing equilibrium at a new calcium concentration different to that in the applied water. Since the SAR_{adj} does not account for these changes a new term for this is adjusted R_{Na} ($Adj\ R_{Na}$) was suggested and calculated from the following equation (Suarez, 1981)

$$Adj\ R_{Na} = \frac{Na}{\frac{\sqrt{Ca_x + Mg}}{2}} \quad \text{-------------------------- (7)}$$

Where,

Na^+ = sodium in irrigation water, me L^{-1}

Ca_x^{2+} = a modified calcium concentration value taken form Table 6 in me L^{-1}. Ca_x^{2+} represents Ca^{2+} in the applied irrigation water but modified due to salinity of the applied water, its HCO_3^-/Ca^{2+} ratio (HCO_3^- and Ca^{2+} in me L^{-1} and the estimated partial pressure of CO_2 in the surface few millimeter of soil (pCO_2 = 0.007 atm).

Mg^{2+} = Magnesium in the irrigation water me L^{-1}

The $Adj\ R_{Na}$ obtained is used in place of the SAR or SAR_{adj} to more efficiently evaluate the potential of water to cause an infiltration problem if used for irrigation. In a study Hameed *et al* (2010) compared SAR, SAR_{adj} and $Adj\ R_{Na}$ of treated waste water and reported that SAR ranged from 1.43 to 3.19 (mean = 2.11), while SAR_{adj} and $Adj\ R_{Na}$ values ranged from 2.35 to 4.40 (mean = 3.12) and from 1.52 to 3.03 (mean = 2.03) respectively.

Residual sodium carbonate

In irrigation waters containing high concentrations of bicarbonates (HCO_3^-) and carbonates (CO_3^{2-}) ions, there is a tendency for calcium and to a lesser extent magnesium to precipitate in the form of carbonates as the soil solution becomes more concentrated, thus leading to increase in SAR of soil solution and consequently increase in ESP of the soil. Eaton (1950) assumed that all calcium and magnesium would precipitate as carbonates and proposed the concept of “Residual Sodium Carbonates” (RSC) for evaluating high carbonate water.

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad \text{------------------------ (8)}$$

Where, the concentration of ions is expressed in meq L^{-1}.

Eaton proposed following irrigation water evaluation based on RSC values:

Table 8: Irrigation water evaluation based on RSC values

RSC value (meq L^{-1})	***Irrigation water evaluation***
< 1.25	Safe for irrigation purpose
1.25-2.5	Marginal suitability for irrigation purpose
> 2.5	Not suitable for irrigation purpose

The relative tolerance of few crops to application of high RSC is presented in table 9. It is observed that with increase in RSC levels there is a significant yield reduction irrespective of crops.

Table 9: Crop yields as affected by irrigation with alkali water in a sandy loan soil at Agra, India.

RSC (me/l)	***Crop yield (t/ha)***			
	Wheat	***Pea***	***Gram***	***Lentil***
Control	4.04	1.33	0.76	1.38
5	3.98	1.22	0.69	1.25
10	3.87	0.93	0.50	1.11
15	3.43	0.86	0.34	1.05

20	3.04	-	-	-
CD (5%)	0.20	0.34	0.22	0.15

Source : S.K. Gupta, 2010

In a recent study Hameed *et al* (2010) obtained negative RSC value in treated municipal waste water indicating no complete precipitation of calcium and magnesium.

3. Toxicity hazards

Toxicity may or may not be associated with salinity or soil permeability problems. Toxic elements that may cause concern under specific condition include boron, chlorides, sodium and other trace elements.

Boron, although an essential element, becomes toxic if present in excess even at relatively very low concentration of 0.6 mgL^{-1}. Toxicity occurs with the uptake of boron from the soil solution. The boron tends to accumulate in the leaves until it becomes toxic to the leaf tissue and results in the death of the plant. In arid regions, boron is considered the most harmful element in irrigation water. Boron is also present in irrigation water as unionized boric acid expressed as boron element (B) in mgL^{-1}. Sensitivity to boron encompasses a wide variety of field and tree crops, although fruit, nut and berry crops are particularly sensitive. On the basis of B content (mgL^{-1}) and the toxicity effect there are 5 classes of irrigation water (Bigger and Nielsen, 1972) as given in table 10.

Table 10: Classification of irrigation water based on boron (B) content

Boron **(mgL^{-1})**	***Toxicity Hazard***
< 0.5	Safe for sensitive crop
0.5 – 1.0	Sensitive crops will show slight to moderate injury
1.0 - 2.0	Semi tolerant crops will show slight to moderate injury
2.0 -4.0	Tolerant crops will show slight to moderate injury
> 4.0	Hazardous for nearly all crops

Other trace elements

In some areas, toxic levels of selenium occur in well water. It has been reported that lithium in well water is toxic to citrus. Industrial pollution of natural water with copper, nickel, cadmium and other toxic heavy metals can also occur. These inputs to the environment are man made and can be controlled by cleaner technology and by strict guidelines (Peter *et al*., 2001). There are two important guidelines for irrigation water quality; 1. Even if toxicity levels of the element remain below accepted irrigation water quality standard, it accumulates in the soil of irrigated crop field if output is below input, 2.Excessive concentration in soil and water have adverse impacts on crop growth and development that lead to immediate hazard to the aquatic and terrestrial lives. Hence sustainability principles are required to minimize this accumulation of toxic elements in agricultural soils.

The accumulation of a given substance ($M_{accumulation}$) in irrigated land can be expressed;

$$M_{accumulation} = \sum_{i=1}^{n} \Delta M_i \quad \text{------------} \quad (9)$$

Where,

ΔM_i = the change in concentration of the substance in the soil in a specific time interval (i), which can be explained by the simplified mass-balance equation;

$$\Delta M_i = M_{in} - M_{drain} - M_{grain} - M_{process}$$

Where,

M_{in} = the mass of the substance imported to the field through irrigation water, fertilizer, atmosphere or other sources.

M_{drain} = the mass exported from the field through surface and subsurface drainage.

M_{grain} = the mass taken up by crops and via the grain exported out of the system.

$M_{process}$ = relevant in the case of e.g. pesticides where a substance can disintegrate into other components due to temperature, sunlight exposure, bacterial activity etc., or in the case of microorganisms (e.g. helminthes and bacteria) where a die off will happen over time due to the same factors.

It is observed from the above equation that ΔMi must be equal or less than zero to avoid accumulation in the soil. It also indicates that to lower ΔM_i either a reduction in M_{in} or an increase in M_{drain} or M_{grain} has to be achieved. M_{drain} or M_{grain} can to a certain degree be controlled either by improved drainage or by specific crop selection. $M_{process}$ is on the other hand more dependent on the climate and soil conditions and therefore difficult to control. Guidelines concerning the maximum permissible levels of various trace elements in irrigation water have been reported in table 11 (FAO, 1985). Siddiqui (1995) also reported the same value for Zn, Mn, Pb, Ni, Co, and Cd to judge the suitability of irrigation water. Besides he fixed 0.2 mgL^{-1} for copper (Cu) and 0.5 mgL^{-1} for iron (Fe) as the maximum limit for irrigation.

Table 11: Recommended maximum concentration of Trace Elements in irrigation water (FAO, 1985)

Elements	***For water used continuously on all soils (mgL^{-1})***
Aluminium	5.0
Arsenic	0.1
Beryllium	0.1
Cadmium	0.01
Chromium	0.1
Cobalt	0.05
Fluorine	1.0
Iron	5.0
Lead	5.0
Lithium	2.5
Manganese	0.2
Molybdenum	0.01
Nickel	0.2
Selenium	0.02
Zinc	2.0

Table 12: FAO guidelines for evaluation of irrigation water quality

Sl No.	FAO guidelines for evaluation of irrigation water quality				
	Soil property affected	Units	Water quality guidelines		
			No problem	Increasing problem	Severe problem
1	Crop water availability	EC_{iw} (dS/m)	0.7	0.7 – 3.0	> 3.0
2	Permeability (Adj. SAR)	Montmorillonite	< 6.0	6.0 – 9.0	> 9.0
		Illite - Vermiculite	< 8.0	8.0- 16.0	> 16
		Kaolinite - Sexquioxide	< 16.0	16.0- 24.0	>24
3	Specific ion toxicity for sensitive crops	Sodium (Na) –Adj. SAR	< 3.0	3.0 – 9.0	>9.0
		Chloride (Cl) – me/L	< 4.0	4.0 – 10.0	> 10.0
		Boron (B)- mg/L	< 0.7	0.7 – 2.0	> 2.0
4	Miscellaneous effect for susceptible crops with sprinkler and drip	Nitrogen (NO_3^- or NH_4^+) – mg/L	< 5.0	5.0 – 30.0	> 30.0
		Bicarbonate(HCO_3^-) - me/L	< 1.5	1.5 – 8.5	> 8.5
5	pH (may cause imbalance in nutrient uptake)	pH	6.5 – 8.5		Very low or very high

Source: London, 1984

High concentration of heavy metals in irrigation water can result in death of crops, interfere with uptake of other essential nutrients or form objectionable deposits in fruits and render edible portion of plants toxic to human and grazing animals (*Aikman, 1983*).

In a study in Subernarekha command area, Kumar et al. (2015) reported that the Zn, Pb and Ni content were below the maximum concentration of irrigation water in well, tank, canal, borewell and river. However content of Co and Cd showed very high values. Higher content of Cu, Fe and Mn were found in well (0.123 mg L^{-1}) and tank (0.626 mgL^{-1}) and canal (0.192 mg L^{-1}), respectively.

Hydrogen Ion Activity (pH)

For assessing irrigation water quality very less attention has generally been paid to pH. The normal range for irrigation water as per *FAO (1985)* guidelines is 6.5-8.5. *Bichi and Bello (2013)* reported that the pH values in surface and ground water used for irrigation ranged from 6.71 to 8.07 and 6.20 to 6.71 respectively. Nazif *et al.* (2006) reported that the average pH of canal water and river water ranged from 8.1 to 8.3 and 8.4 to 8.9 respectively. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion (Ayers and Westcot, 1985 & Pescod, 1985).

The water with high RSC has high pH and land irrigated by such waters becomes infertile owing to deposition of sodium carbonate.

In a study Abdel-Ghaffar *et al.*, 1988 reported that municipality waste water contained a number of potentially toxic elements such as arsenic, chromium, copper, lead, mercury, zinc etc. Even if toxic materials were not present in concentrations likely to affect humans, they might well be at phyto-toxic levels, which would limit their agricultural use. Saraswat *et al.* 2005 suggested that continuous use of raw sewage water generally led to built up of metals and organic residues in the soils depending upon composition, rate and frequency of sewage-irrigation as well as characteristics of the soil. Sometimes built up of metals in agricultural soils may create phyto-toxicity to crops (Paul *et al.* 2006), which warrants judicious use of sewage and other waste water.

Effect of waste water use on soils

Study conducted by Raychoudhuri *et al.* (2014) on impact of waste water on surface soil showed an increase in Fe, Mn, Cr and Pb concentration by 13, 94, 72 and 71 per cent respectively. Accumulation of heavy metals due to waste water was conspicuous and the enrichment of heavy metals in the waste water irrigated soils were in the order, Fe > Zn > Mn = Cd > Cr > Cu. There is a number of different water quality guidelines associated with irrigated agriculture. Because of wide variability in crop and field condition, none is completely acceptable. The modified guideline by *Ayers and Westcot (1985)* was found to be the most reliable to predict the water quality for irrigation.

Water Quality Index (WQI)

Water quality index is a new tool for quantitative assessment of water quality in relation to a particular function. It is computed as;

$$WQI = \sum_{i=1}^{n} W_i \times q_i$$

Where;

W_i = Relative weight assigned to a particular quality parameter calculated on the basis of its relative importance as computed to other parameter.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

Where;

w_i = the weight of each parameter and n is the number of parameters

q_i = the quality rating scale of each parameter is computed by dividing the observed value by its standard value as per the guidelines laid down in the BIS 10500, 1991 or FAO and multiplying with 100

$$q_i = \frac{c_i}{s_i} \times 100$$

The computed value of WQI is then interpreted using WQI rating classes. There are 4 rating classes of WQI for assessing ground water quality for irrigation purposes based on restrictions, viz, none, slight, moderate and severe with WQI values < 150, 151-300, 301-450 and > 450 respectively (Raychoudhury *et al*., 2014).

Special consideration for water quality guidelines as suggested by Paliwal (1972) and Ras *et al.* (1994) are as follows.

1. Use gypsum when saline waters (having SAR > 20 and Mg/Ca ratio > 3 and rich in silica) induce water stagnation during rainy season and crops grown are sensitive to it.
2. Leaving the field fallow during the rainy season is helpful when SAR > 20 and waters of higher salinity are used in low rainfall areas.
3. Additional phosphorus fertilization is beneficial, especially when Cl^{-}/SO_4^{2-} ratio in water is > 2.0
4. Canal water preferably be used at early growth stages including pre-sowing irrigation for conjunctive use with saline waters.
5. If saline water is to be used for seeding of crops, 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will ensure better germination.
6. When EC_{iw} < EC_e (0 - 45 cm soil at harvest of rabi crops), saline water irrigation just before the onset of monsoon will lower soil salinity and will raise the antecedent soil moisture for greater salt removal by rains.
7. Use of organic materials in saline environment enhances yields.
8. Accumulation of B, NO_3, Fe, Si, F, Se and heavy metals beyond critical limits proves toxic. Expert advice prior to the use of such waters may be obtained.
9. For soils having (i) shallow water table within 1.5 mm in kharif season and (ii) hard sub soil layers, the next lower EC w/alternate mode of irrigation canal/saline) is applicable.

Conclusion

The problems that result from the use of a particular irrigation water, vary both in kind and degree, and are modified by soil, climate and crop as well as by the skill and knowledge of the water user. As a result there is no set limit on water quality, rather its suitability for use is determined by the conditions of use which affects the accumulation of water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems.

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