Review Article

Irrigation Water Quality and Soil Management

**Abstract**

Injudicious use of irrigation water repeatedly over the time with high water demanding crops on clay dominating soils causes salt affected soils with problems like reduced permeability and poor drainage in arid and semiarid regions and around canal command areas. The soils with rich in clay with impeded drainage unable to each out salts effectively. Further less use of organic manures, imbalanced fertilization, denial for soil and irrigation water testing, same type of fertilizer use, multi-nutrient deficiencies, less response ration from different soils, no inclusion of green manuring crops. The main way that irrigation water quality affects soil health is by influencing its salinity levels through the accumulation of dissolved salts. If the water contains too many minerals, especially sodium, it can negatively affect plant growth and soil structure. The quality of irrigation waters differs in various regions, countries and locations based on how the groundwater has been extracted and used, the rainfall intensity and subsequent aquifer recharge. The use of groundwater for agriculture in hot arid and semiarid countries where rainfall is scarce leads to increase groundwater salinity and limits the selection of crops for cultivation. It is therefore important to determine the irrigation water quality. The concentration and composition of soluble salts in water determines its quality for irrigation. Four basic criteria for evaluating water quality for irrigation purposes are described, including water salinity (EC), sodium hazard (sodium adsorption ratio-SAR), residual sodium carbonates (RSC) and ion toxicity. Toxicities of boron and chlorides to plants are described. More specifically the relative tolerance levels of plants to boron is tabulated for easy understanding.

Keywords: irrigation, cultivation, Soil Management, water quality

**Introduction**

The modified guideline by Ayers and Westcot, 1985 was found to be the most reliable to predict the water quality for irrigation. The suitability criterion of water for agriculture is determined not only by the total amount of salt present but also by the type of salt. Many soil and crop related problems are incurred as the total salt content increases. Special management practices may be required to maintain desirable crop yields. Water quality for use in agriculture is judged on the potential severity of problems that can be expected to be developed during long-term use. The process is slow and gradual so one must be very careful about the quality of water. Irrigation water quality is being evaluated based on the chemical and physical characteristics of the water and only rarely are any other factors considered important (FAO 1985).

Nearly all waters contain dissolved salts and trace elements, many of which result from the natural weathering of the earth’s surface. In most irrigation situations, the primary water quality concern is salinity levels, since salts can affect both the soil structure and crop yield. Generally many types of salts exist and are commonly found in most of the irrigation water resources. Most salinity problems in agriculture result directly from the salts carried in the irrigation water. As water moves through capillary action towards soil surface, water gets evaporated from the soil surface with accumulation of dissolved salts over the surface and in the vicinity of rhizosphere (secondary salinization). Numerous parameters are used to define irrigation water quality, to assess salinity hazards, and to determine appropriate management strategies.

**Materials and method**

# Criteria and standards for assessing irrigation water quality

Water quality requirements for different uses of water are scientifically termed as criteria and the permissible level of contaminants in water for different uses without any negative impact on environment and society are termed as Standards. As per Gupta and Gupta 2003 the characteristics of irrigation water that have been the most important in determining its quality, depends upon climatic condition, irrigation practices, soil water retention characteristics, crop tolerance, depth to water table and agronomic practices etc.

The criteria for assessing the quality of irrigation developed by Richards L.A., (1954) is still widely used all over the world.

# Criteria for assessing quality of irrigation water:

* 1. Total concentration of soluble salts (EC) and pH
  2. Relative concentration of sodium to other cations (SAR)
  3. Bicarbonate concentration in relation to calcium and magnesium
  4. Concentration of specific ions

There are some derived parameters based on the concentration of cations and anions in irrigation water used for assessing the intensity of salinity or sodicity in relation to soil physical, chemical and biological properties along with crop response.

# Derived parameters based on water testing:

* 1. Hardness of water
  2. Mg/Ca ratio
  3. Permeability index (PI)
  4. Kelley’s ratio
  5. Soluble sodium percentage
  6. Magnesium hazard

# Criteria for assessing quality of Irrigation water:

* 1. **Total concentration of soluble salts (EC) and pH**

Water with high salinity is toxic to plants and poses a salinity hazard. Soils with high levels of total soluble salts (salinity) are called saline soils. A high concentration of soluble salts in the soil lowers the osmotic potential of water that result in a “physiological” drought condition. That is, even though the field appears to have plenty of moisture, the plants wilt because the roots are unable to absorb the water. Water salinity is usually measured by the TDS (total dissolved solids) or the EC (electric conductivity). TDS is sometimes referred to as the total salinity and is measured or expressed in parts per million (ppm) or in the equivalent units of milligrams per liter (mg/L). EC is actually a measurement of electric current and is reported in one of three possible units. Subscripts are used with the symbol EC to identify the source of the sample. ECiw is the electric conductivity of the irrigation water. ECe is the electric conductivity of the soil saturated paste extract of a soil taken from the root zone. ECd is the soil salinity of the saturated extract taken from below the root zone. ECd is used to determine the salinity of the drainage water which leaches below the root zone.

**Results and discussion**

It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability and activity of soil microorganisms which influence key soil processes. Excess salts hinder plant growth by affecting the soil-water balance. Soils containing excess salts occur naturally in arid and semiarid climates. Salt levels can increase as a result of cropping, irrigation, and land management. Saline soils and salty water conduct more electricity than non-saline soils or pure water (table 1). It is

the ions that pass or conduct electricity from one ion to the next. The rating for EC of irrigation water is stated as in table 2. Further guidelines for interpretation of IW quality based on EC as per soil type are also stated in Table 3.

* + - Salt concentration increases in IW: EC also increases.
    - Acidic or low pH solutions also exhibit high EC
    - Expressed in dS m-1 (SI units) or mmhos cm-1
    - TDS (mg/L) = EC (dS m-1) x 640

**Table 1: Electrical conductivity of different water**

|  |  |  |
| --- | --- | --- |
| **Sr.No.** | **Type of water** | **EC (dS m-1)** |
| 1 | De-ionized water | 0.0005 to 0.002 |
| 2 | Sea water | 40 to 55 |
| 3 | Poor quality irrigation water | >3.0 |

**Table 2: Ratings for EC of irrigation water**

|  |  |  |  |
| --- | --- | --- | --- |
| **Water class** | **EC (dS m-1)** | **Salt (g lit-1)** | **Suitability** |
| C1= low salinity | 0.1 to 0.25 | < 0.16 | Safe with likelihood of any salinity problem |
| C2= Medium salinity | 0.25 to 0.75 | 0.16 to 0.50 | Will need moderate leaching |
| C3= High salinity | 0.75 to 2.25 | 0.5 to 1.5 | Cannot be used on soils with restricted drainage/clay soils |
| C4= Very high salinity | 2.25 to 5.00 | 1.5 to 3.00 | Unsuitable under ordinary conditions |

**Table 3: Guidelines for interpretation of water quality based on EC for irrigation under Indian condition (Bhumbla and Abrol, 1972).**

|  |  |  |
| --- | --- | --- |
| **Upper permissible limit of**  **EC of water for safe use for irrigation, dS/m** | **Crops to be grown** | **Soil type** |
| 1.5 | Semi- tolerant | Deep black soils and alluvial soils having a  clay content of more than 30 percent. Soils that are fairly to moderately well drained |
| 2 | Tolerant |
| 2 | Semi-  tolerant | Heavy textured soils having clay content of 20-30%. Soils that are well drained  internally and have a good surface drainage system. |
| 4 | Tolerant |
| 4 | Semi- tolerant | Medium textured soils having a clay content of 10-20%. Soils that are very well drained internally and have a good surface  drainage system. |
| 6 | Tolerant |
| 6 | Semi-  tolerant | Light textured soils having a clay content  of less than 10%. Soils that have excellent internal and surface drainage |
| 8 | Tolerant |

**Total dissolved salts (TDS)**

IW includes major ions, *i.e*. Ca2+, Mg2+, Na+, K+, CO32−, HCO3−, Cl−, SO42− and PO43−. After evaporation of water, accumulation of salt at the root zone makes obstacle to plants by which they are not capable of absorbing water from soil resulting in moisture stress. The irrigation water suitability on the basis of TDS as stated in table 4. Further, approximate amount of salt added through irrigation water for one hectare of sugarcane is also mentioned in table 5.

# Table 4: Total dissolved salts rating

|  |  |  |
| --- | --- | --- |
| **Sr.No.** | **TDS Rating** | **Rating (mg/L)** |
| 1 | Preferred | < 450 |
| 2 | Slight to moderate | 450-2000 |
| 3 | Unsuitable | > 2000 |

FAO 2006

**Table 5: Approximate salts added in one hectare sugarcane based on EC of IW**

|  |  |  |  |
| --- | --- | --- | --- |
| **EC of IW (dS m-1)** | **Amount of salt**  **added in one irrigation (Kg)** | **Total number of irrigations** | **Total amount of salt in crop cycle (Kg)** |
| 0.5 | 192 | 25 | 4800 |
| 1.0 | 384 | 25 | 9600 |
| 1.25 | 480 | 25 | 12000 |
| 1.50 | 576 | 25 | 14400 |
| 2.0 | 767 | 25 | 19200 |

# Effect of EC on yield reduction potential of different crops

The primary effect of high ECw water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire “pure” water, usable plant water in the soil solution decreases dramatically as EC increases. The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high ECw reduces yield potential. Actual yield reductions from irrigating with high EC water vary substantially. Factors influencing yield reductions include soil type, drainage, salt type, irrigation system and management. Beyond effects on the immediate crop is the long term impact of salt loading through the irrigation water (table 6). The salt tolerance of a crop may be appraised according to three criteria:

1. The ability of the crop to survive on saline soils
2. The yield of the crop on saline soil and
3. The relative yield of the crop on a non-saline soil under similar growing condition.

**Table 6.Potential yield reduction from saline water for selected irrigated crops**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Crops** | **Per cent yield reduction** | | | |
| **0%** | **10%** | **25%** | **50%** |
| **EC of the irrigation water (dS m-1) at 25oC.** | | | |
| Barley | 5.3 | 6.7 | 8.7 | 12 |
| Wheat | 4.0 | 4.9 | 6.4 | 8.7 |
| Sugarbeet | 4.7 | 5.8 | 7.5 | 10 |
| Alfalfa | 1.3 | 2.2 | 3.6 | 5.9 |
| Potato | 1.1 | 1.7 | 2.5 | 3.9 |
| Corn (grain) | 1.1 | 1.7 | 2.5 | 3.9 |
| Corn (silage) | 1.2 | 2.1 | 3.5 | 5.7 |
| Onion | 0.8 | 1.2 | 1.8 | 2.9 |
| Dry Beans | 0.7 | 1.0 | 1.5 | 2.4 |
| *Source: Ayers R.S. (1977)* | | | | |

# pH:

**Alkaline water:** This water may contain high concentration of bicarbonates

(HCO3) (Generally water has pH 8.0 and above) and carbonates (CO3) (generally pH 9 and above). This can cause calcium and magnesium to precipitate from the soil, which can affect plant growth. Some trace elements, like copper and zinc will also be less available to the plant in this situation.

**Acidic water:** This type of water also have a detrimental effects on plant growth, particularly causing nutritional problems, while strongly acidic water (below pH 4) can contribute to soil acidification. A pH less than 6 indicates corrosiveness, which can lead to damage to metal pipes, tanks and fittings.

# Relative concentration of sodium to other cations (SAR)/ Sodium Hazard

The sodium hazard of irrigation water is expressed as the ‘sodium adsorption ratio (SAR)’. Sodium contributes directly to the total salinity and may also be toxic to sensitive crops, such as fruit trees. The main problem with a high sodium concentration is its effect on the physical properties of soil (structure degradation). It is, thus, recommended to avoid using water with an SAR value greater than 10, if the same water will be the only source of irrigation for long periods then either it should be used on coarse textured soil or needs sufficient drainage (table 7)

Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil–a situation caused by excessive amounts of adsorbed sodium on soil colloids. This breakdown in the soil physical structure, results in the dispersion of soil clay and that causes the soil to become hard and compact when dry, and increasingly impervious to water penetration (due to dispersion and swelling) when wet. Fine textured soils, those high in clay, are especially subject to this action. When the concentration of sodium becomes excessive (in proportion to calcium plus magnesium), the soil is said to be sodic. If calcium and magnesium are the predominant cations adsorbed onto the soil exchange complex, the soil can be easily tilled and will have a readily permeable granular structure.

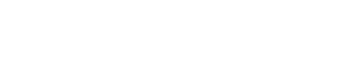
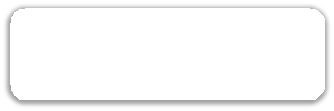
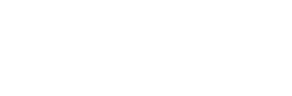
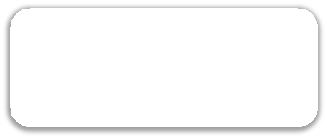
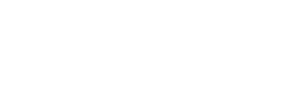
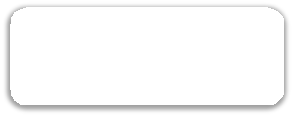
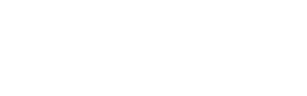
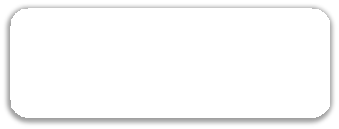
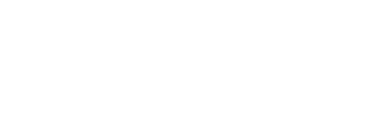
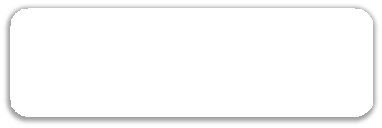
The permissible value of the SAR is a function of salinity. High salinity levels reduce swelling and aggregate breakdown (dispersion), thus promoting water

penetration. A high proportion of sodium, however, produces the opposite effect as stated in Figure 1.

# Table 7: Sodicity classes of irrigation water

(USSL Staff [1954](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR14))

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr.No.** | **SAR** | **Sodicity class** | **Suitability** |  |
| 1 | <10 | S1 | Low |
| 2 | 10-18 | S2 | Medium |
| 3 | 18-26 | S3 | High |
| 4 | >26 | S4 | Very high |



Na+ is a monovalent enhances zeta potential therby thickness of DDL increases and dispersion of claytakes place

Surface crusting, higher water content

Structure get desproyed, sealing of micro and macro pores

IW with high SAR shows displacement of Ca2+ and Mg2+ from clay by Na+

Soil becomes compact, BD high, low internal water movement

**Figure 1: Effects of high sodium from irrigation water on soil**

# Sodium hazard (Adjusted Sodium Adsorption ratio)

The presence of sodium ions represents a potential sodium hazard to the soil. The sodium hazard is associated with an exchangeable sodium percentage value of more than 15. The criterion currently used to define a sodic condition is the analytically determined sodium-adsorption ratio (SAR). The reason is that the SAR can be calculated from analysis of saturation paste extract of salt affected soils. The determination of exchangeable sodium percent is time consuming. The SAR of irrigation water gets modified after it becomes soil water due to several factors like evapo-transpiration, salt concentration, dissolution, salt precipitation and mineral weathering during irrigation. Considering all these factors empirical equation was developed by Rhoades, 1968 to estimate the ESP of the surface soil from the sodium adsorption ratio value of the applied irrigation water (SARiw) which was called as adjusted-sodium adsorption ratio (SARadj) (table 8 )

SARadj = SARiw (1 + (8.4 – pHc\*)……[1] SARadj = SARiw (9.4-pHc)

|  |  |  |
| --- | --- | --- |
| **Sr.No.** | **Rating** | **Suitability** |
| 1 | Safe | < 1.25 |
| 2 | Marginal | 1.25 to 2.5 |
| 3 | Unsuitable | >2.5 |
| (Eaton [1950;](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR6) Wilcox et al. [1954*)*](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR16) | | |

The term pHc is defined as the theorotial pH of irrigation water with a given Ca, Mg, HCO3 and CO3 concentration, which is in equilibrium with solid CaCO3 present in soil.

When the value of (8.4-pHc) for irrigation water is more than zero, CaCO3 precipitates’ in the soil when this irrigation water applied. However if the value is less than zero, the irrigation water dissolves CaCO3, if present in the soil.

The term pHc is calculated from

pHc = (pK2 - pKc) + p (Ca + Mg) + p (HCO3 + CO3)……[2]

All the concentrations are in mill equivalents per liter.

The term pK2 and pKc are the negative logarithms of the second dissociation constant of H2CO3 and the solubility product of titrable base and is closely related to the alkalinity of the water.

**Table 8: Permissible limits of SARadj in relation to sodium hazard.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr.**  **No.** | **Clay mineral nature** | **Adjusted SAR value** | | |
| **No problem** | **Moderate problem** | **Severe problem** |
| 1 | Montmorrilonite 2:1 mieral | < 6 | 6-9 | >9 |
| 2 | Illite-vermiculite 2:1 mieral | <8 | 8-16 | >16 |
| 3 | Kaolinite sesquixide 1:1 mieral | <16 | 16-24 | >24 |

Source: London 1984.

The adjusted SAR should be evaluated for such water which have EC higher than

1.5 and less than 3.0 dS m-1 because only this group of water are more likely to have twin problem of RSC and SAR.

**c. Residual Sodium Carbonates (RSC):**

RSC represent as the amount of sodium carbonate (NaCO3) and sodium bicarbonate (NaHCO3) present in the irrigation water if the concentration of carbonate (CO32−) and bicarbonate (HCO3−) ions exceeds the concentrations of Ca2+ and Mg2+ ions (Raghunath [1987](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR33)), precipitation of Ca2+ and Mg2+ takes place. If the carbonates are less than alkaline earths (Ca2+ + Mg2+), it outlined the residual NaCO3 which is absent. Generally, RSC is expressed as mill equivalents per liter (meq/l) of NaCO3. An excess of CO32− and HCO3− causes precipitation of soil Ca2+ and Mg2+ impairing the soil structure as well as potentially activating soil sodium (table 9). This approach is based on the equation:

**RSC (meq l−1) = (CO2−3+HCO−3) − (Ca2++Mg2+)**

Where, all the concentrations are in meq L−1.

**Table 9: RSC and suitability of water for irrigation**

# Specific Ion Toxicity

* 1. **Boron:**

Boron is essential to the normal growth of all plants, but the amount required is low. If it exceeds a certain level of tolerance depending on the crop, then boron may cause injury. The range between deficiency and toxicity of boron for many crops is narrow. In order to sustain an adequate supply of boron to the plant at least 0.02 ppm of boron in the irrigation water may be required. However, to avoid toxicity, boron levels in irrigation water should, ideally, be lower than 0.3 ppm (table 10). Higher concentrations of boron will likely require that the intended crop type must first be evaluated with respect to its boron tolerance. Boron is weakly adsorbed by soils. Thus, its actual root-zone concentration may not vary in direct proportion to the degree that boron sourced from the irrigation water has been concentrated in the plant during growth.

Symptoms of boron injury may include characteristic leaf ‘burning’, chlorosis and necrosis, although some boron sensitive species do not develop obvious symptoms. Boron toxicity symptoms first appear on older leaves as yellowing, spotting, or drying of leaf tissues at the tips and edges. The drying and chlorosis often progresses toward the center of the leaf, between the veins as boron accumulates over time (figure 2) (Ayers and Westcot [1985](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR2)). Table [11](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#Tab2) describes the effects of a range of boron concentrations in irrigation water for different crops (Bauder *et al*. [2011](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR4)).

**Table 10: Relative tolerance of plants to boron**

|  |  |  |
| --- | --- | --- |
| **Sr.No.** | **Boron concentration**  **(ppm)** | **Effect on crops** |
| **1** | < 0.5 | Satisfactory for all crops |
| **2** | 0.5–1.0 | Satisfactory for most crops |
| **3** | 1.0–2.0 | Satisfactory for semi-tolerant crops |
| **4** | 2.0–4.0 | Satisfactory for tolerant crops only |

(Follett and Soltanpour [2002](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR4); Bauder *et al*. [2011](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR4))

**Table 11: Boron concentration (ppm) in irrigation water for different crops**

|  |  |  |  |
| --- | --- | --- | --- |
| **Boron class** | **Sensitive crops** | **Semi-sensitive crops** | **Tolerant crops** |
| 1 | < 0.33 | < 0.67 | < 1 |
| 2 | 0.33 – 0.67 | 0.68 – 1.33 | 1 – 2.0 |
| 3 | 0.68 to 1.00 | 1.34 – 2.00 | 2.01 – 3.0 |
| 4 | 1.01 – 1.25 | 2.01 – 2.50 | 3.01 – 3.75 |
| 5 | > 1.25 | > 2.5 | > 3.75 |

(Bauder *et al.* [2011](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR4)and Scofield, C.S. (1936)

(Ludwick *et al.* [1990](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR9); Bauder *et al.* [2011](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR4))

|  |  |
| --- | --- |
| C:\Users\Admin21\Desktop\B.jpg | C:\Users\Admin21\Desktop\BueB8TwCUAEVEEx.jpg |
| Figure 2: Boron toxicity symptoms on paddy and grape. | |
| Source: Source: IRRI, Cuttack [www.pthorticulture.com](http://www.pthorticulture.com/) & [www.krugerseed.com](http://www.krugerseed.com/) | |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ii.** | **Chloride Toxicity** | | | | |
| The chloride (Cl−) anion occurs in all waters; chlorides are soluble and leach readily with drainage water. Chlorides are necessary for plant growth, though in high concentrations they can inhibit plant growth and can be highly toxic to some plant species. Water must, thus, be analyzed for Cl− concentration when assessing water quality. Table 12 shows Cl− levels in irrigation water and the effects of on crops. Ayers and Westcot ([1985](https://link.springer.com/chapter/10.1007/978-3-319-96190-3_5#CR2)) reported that Cl− toxicity on plants appears first at the leaf tips which are a very common symptom for chloride toxicity and progresses from the leaf tip back along the edges as severity of the toxic effect increases. Excessive necrosis is often accompanied by early leaf drop or even total plant defoliation (Figure 3).  **Table 12: Chloride levels of irrigation waters and their effects on crops** | | | | | |
|  | | **Cl− concentration** | | **Effects on crops** |  |
|  | |  | |  |  |
| **meq L-1** | **ppm** |  |
| < 2 | < 70 | Generally safe for all plants |
| 2–4 | 70–140 | Sensitive plants usually show slight to  moderate injury |
| 4–10 | 141–350 | Moderately tolerant plants usually show slight to substantial injury |
| > 10 | > 350 | Can cause severe problems |

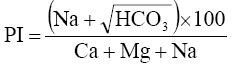
|  |  |
| --- | --- |
| C:\Users\Admin21\Desktop\cl-tox-grapevine.jpg | Salt damage to soybean from irrigation. Source: Dr. Gordon Johnson, University of Delaware. |
| Figur 3. Chloride toxicity symptomes in grape and soybean. | |

# Derived parameters used to assess the quality of irrigation water:

* 1. Permeability index (PI)
  2. Sodium percentage
  3. Kelley’s ratio
  4. Magnesium hazard
  5. Potential salinity
  6. Hardness of water

# Permeability Index:

The permeability index (PI) is an indicator to study the suitability water for irrigation purpose. Water movement capability in soil (permeability) is influenced by the long-term use of irrigation water (with a high concentration of salt) as it is affected by Na+, Ca2+, Mg2+ and HCO3− ions of the soil. PI formula has been developed by Doneen ([1964](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR9)), to assess water movement capability in the soil as the suitability of any kind of source of water for irrigation. As per the Doneen, 1964, if irrigation water falls in Class I (>75%) of PI, then water movement capability in soil is higher than that of Class II (25-75%) and III (<25%) Table 13 Figure 4.



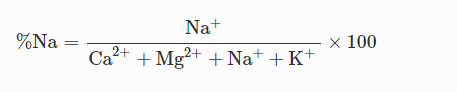
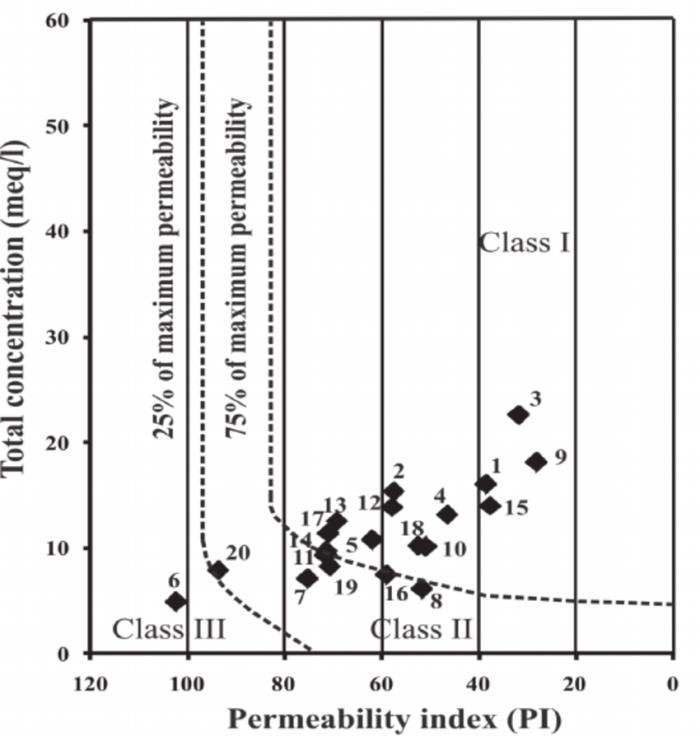
**Table 13: Ratings of Permeability Index**

*Doneen* [*(1964*](https://link.springer.com/article/10.1007/s13201-018-0866-8)*)*

All the ion concentrations are expressed in meq L-1

|  |  |  |
| --- | --- | --- |
| **PI class** | **Rating** | **Suitability** |
| Class I | >75 % | Suitable |
| Class II | 25-75% | Good |
| Class III | <25% | Unsuitable |

**Figure 4: Permeability index and movement of water in soil.**



# Percent sodium (%Na) or sodium hazard

The percent sodium is also used in classifying water for irrigation purpose. Na+ is important parameter and helps in categorization of any source of water for irrigation uses. Na+ makes chemical bounding with soil to reduce water movement capacity of the soil. Percent Na+ concentration is a factor to assess its suitability for irrigation purposes. Na+ reacts with CO32− and forms alkaline soils, while Na+ reacts with chloride and forms saline soils. Sodium-affected soil (alkaline/saline) retards crop growth. If concentration of Na+ in irrigation water is high, then the ions tend toward the clay particles, by removing Ca2+ and Mg2+ ions through a base-exchange reaction. This exchange process in soil reduces water movement capacity. In this condition, air and water cannot move freely or restricted during wet conditions, and such soils have become hard when dry.

# Table 14: Ratings of percent sodium

All the ion concentrations are expressed in meq L-1

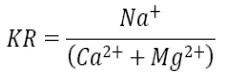
Saleh *et al.* [1999](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR47)

|  |  |
| --- | --- |
| **Rating (%)** | **Suitability** |
| <20 | Excellent |
| 20-40 | Good |
| 40-60 | Permissible |
| 60-80 | Doubtful |
| >80 | Unsuitable |

Khodapanah *et al.* [2009](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR27)

**c. Kelly’s ratio (KR) or Kelly’s index (KI)**

Kelly ([1940](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR26)) and Paliwal ([1967](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR32)) introduced another factor to assess quality and classification of water for irrigation purpose based on the concentration of Na+ against Ca2+ and Mg2+. It can be calculated using as.



All the ion concentrations are expressed in meq L-1

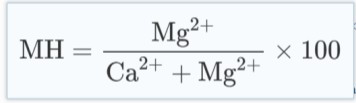
KR or Kelly’s index (KI) > 1 indicates an excess level of Na+ in waters. Therefore, water with a KI ≤ 1 has been recommended for irrigation, while water with KI ≥ 1 is not recommended for irrigation due to alkali hazards. (Ramesh and Elango [2012](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR35)).

**d. Magnesium hazard (MH) or magnesium adsorption ratio (MAR)**

Usually, alkaline earths cations like Ca2+ and Mg2+ ions are linked with soil friability and aggregation, but both are also essential nutrients for the crop. The high value of Ca2+ and Mg2+ in water can increase soil pH therefore soil converting it to saline nature of the soil resulting in decrease in the availability of phosphorous. Excess concentration of magnesium in groundwater affects the soil quality by converting it into alkaline and decreases the crop yield. In the majority of the poor quality ground waters occurring in the arid and semi-arid regions, the concentration of Mg is often greater than that of Ca.

The proportion of Mg over Ca generally increases with an increase in the salinity level of the water. These waters form an important source of irrigation water owing to the scanty and erratic rainfall received in these areas. The use of such waters for irrigation will influence the nutrition and yield of crops. It is believed that one of the important qualitative criteria in judging the irrigation water is its Mg content in relation to total divalent cations. Therefore high Mg adsorption by soils affects their physical properties. A harmful effect on soils appears when Ca: Mg ratio decline below

50. (Ramesh and Elango [2012](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR35); Szabolcs and Darab ([1964](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR58))).



All the ion concentrations are expressed in meq L-1

**e. Potential Salinity (PS):**

PS is another water quality parameter-based index (Doneen [1964](https://link.springer.com/article/10.1007/s13201-018-0866-8#ref-CR9)) for categorization of water for agriculture use.

**PS = Cl + ½ SO42- (All are in me L-1)**

Potential salinity @ 3–15 me L-1 can be recommended for medium permeability soils while 3-7 me L-1 recommended for soils of low permeability

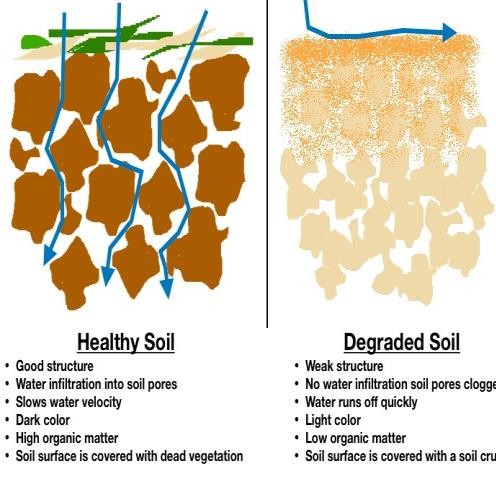
# f. Hardness of water

Irrigation water that contains high levels of dissolved Ca2+ or Mg2+ salts, or both,

is described as being ‘hard’. Other cations such as iron, manganese, aluminum and

zinc can also contribute to hardness. Water hardness is defined in terms of calcium carbonate (CaCO3, also known as ‘lime’). The level of hardness is expressed as the total amount of CaCO3 in milligrams per liter of water (mg/L). Hard water is the water that contains higher concentrations of calcium and magnesium. Presence of sulfates, carbonates, bicarbonates of calcium and magnesium makes water hard (table 16).

Hard water makes land soft while soft water makes land hard. Hard water contains appreciable amount of Ca and Mg. The flocculating power of Ca2+ and Mg2+ is higher than Na and K that causes tight holding of Ca2+ and Mg2+ on clay colloids in fine textured soil. This ultimately decreases zeta potential causing reduction in thickness of double diffuse layer, enhances flocculation of clay, improvement in soil structure, aeration with reduction in bulk density (Table 15 and Figure:5).



|  |  |  |
| --- | --- | --- |
| **Cation** | **Hydrated Radius (nm)** | **Relative Flocculating**  **Power** |
| Na+ | 0.77 | 1.0 |
| K+ | 0.53 | 1.7 |
| Mg 2+ | 1.08 | 27 |
| Ca2+ | 0.96 | 43 |

# Types of Hard Water –

Figure 5: Flocculation and dispersion of clays

**Table15: Relative flocculating**

**power of cations**

Sumner and Naidu 1998

* Temporary hard water (Alkaline hardness)
* Permanent hard water

Temporary hard water contains bicarbonates and carbonates of calcium and magnesium. It is also called alkaline hardness. Permanent hardness of water is due to chlorides and sulfates of calcium and magnesium. It is also called non-alkaline hardness (table 16).

# Table 16: Rating for hardness of water

EPA, 1986

|  |  |  |
| --- | --- | --- |
| **Sr.**  **No.** | **Rating** | **Hardness**  **(Expressed as mg L-1 CaCO3)** |
| 1 | Soft water | Less than 60 |
| 3 | Slightly hard | 60-120 |
| 4 | Hard | 120-180 |
| 5 | Very hard | > 180 |

**Soft Water**

The water which gives lather with soap water is called soft water. It contains lower concentrations of calcium and magnesium. It contains high concentration of sodium ions (Table 17).

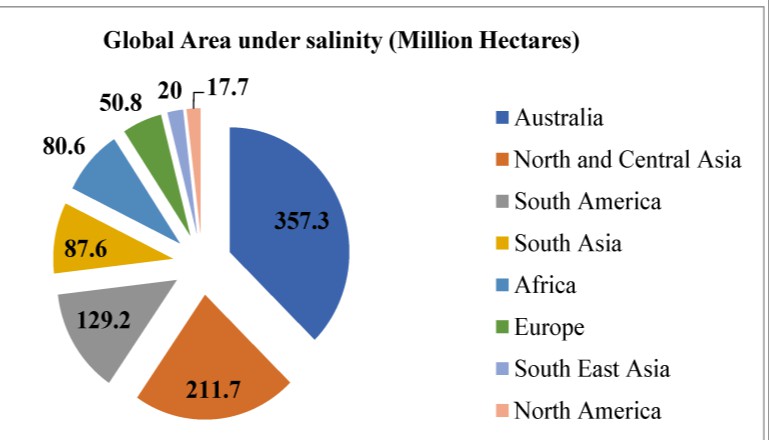
**Table 17. Hard water makes soil soft and soft water makes soil hard**

|  |  |  |
| --- | --- | --- |
| **Concentration of cations in irrigation water** | **Term** | **Effect on soil structure** |
| Low Na+ in relation to Ca2+ and Mg2+(Low SAR) | Hard water | “Soft Soil”, good soil aggregation, structure  and porosity and good drinage |
| High Na+ in relation to Ca2+ and Mg2+(High SAR) | Soft water | “Hard Soil” dispersion of clay and  dissolution of organic matter (Slick spots),  poor soil structure, less porosity soil surface seals, restricted water movement |

# Consequences of Irrigation Water

Groundwater either well or bore well has become the major source of irrigation water along with canal water. Quality of irrigation water, application method, cropping pattern, soil types, quantity and amount of irrigation water is a matter of concerns for the formation of salt affected soil in India and Maharashtra (Table 18). Further composition and concentration of dissolved elements in water can be useful in determining its suitability for irrigation. Now it is very important to test the soil for nutrient status along with assessment irrigation water quality.

World Bank states that soil salinization caused by inappropriate irrigation practices affects about 60 million ha, or 24% of all irrigated land worldwide. In Africa, salinization accounts for 50% of irrigated land. Increasing soil salinization is occurring also in India, Pakistan, China, and Central Asia (CSSRI, Karnal). In Egypt, almost 35% of the agricultural land suffers from salinity (Kim and Sultan, 2002). Soil salinization is the first stage of environmental destruction caused by salinity and is interrelated with river and lake salinization (Figure 6).



***“Soil Management for Climate Smart Agriculture” June 14 to 04 July,2021, Dept. SSAC, MPKV, Rahuri***

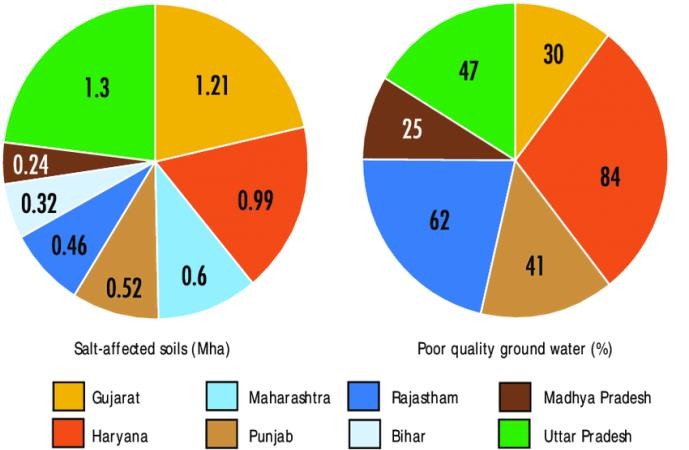
**Figure 6. Gblobal salt affected area**

*Sources:* https://cssri.res.in/*CSSRI, Karnal, Haryana*

# Table 18: Extent and distribution of salt affected soils in India

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr.**  **No.** | **State** | **Saline soils (ha)** | **Alkali soils (ha)** | **Coastal saline soil (ha)** | **Total (ha)** |
| 1 | Andhra Pradesh | 0 | 196609 | 77598 | 274207 |
| 2 | A & N islands | 0 | 0 | 77000 | 77000 |
| 3 | Bihar | 47301 | 105852 | 0 | 153153 |
| 4 | Gujarat | 12,18,255 | 5,41,430 | 4,62,315 | 2222000 |
| 5 | Haryana | 49157 | 1,83,399 | 0 | 232556 |
| 6 | J & K\* | 0 | 17500 | 0 | 17500 |
| 7 | Karnataka | 1307 | 1,48,136 | 586 | 150029 |
| 8 | Kerala | 0 | 0 | 20000 | 20000 |
| 9 | Maharashtra | 1,77,093 | 4,22,670 | 6996 | 606759 |
| 10 | M.P. | 0 | 1,39,720 | 0 | 139720 |
| 11 | Orissa | 0 | 0 | 1,47138 | 147138 |
| 12 | Punjab | 0 | 1,51,717 | 0 | 151717 |
| 13 | Rajasthan | 19,5571 | 1,79,371 | 0 | 374942 |
| 14 | Tamil Nadu | 0 | 3,54,784 | 13231 | 368015 |
| 15 | U.P. | 21989 | 13,46,971 | 0 | 1368960 |
| 16 | West Bengal | 0 | 0 | 4,41,272 | 441272 |
|  | **Total** | **1710673** | **3788159** | **1246136** | **6744968** |

*Sources:* https://cssri.res.in/*CSSRI, Karnal, Haryana*



**12,15,255**

*Sources:* https://cssri.res.in/*CSSRI, Karnal, Haryana*

**1,95,571**

***“Soil Management for Climate Smart Agriculture” June 14 to 04 July,2021, Dept. SSAC, MPKV, Rahuri***

**1349971**

**422670**

**Alkali soil**

**Gujrat Maharashtra**

**Tamilnadu**

**Saline soil**

**1,77,093**

**Figure 7. State wise salt affected soils in India**

**354754**

**541430**

**UP**

***Sources:* https://cssri.res.in/*CSSRI, Karnal, Haryana***

**Rajasthan**

**Gujrat Maharashtra**

# Effects of saline water

Both surface and ground waters contain dissolved salt. Continuous use of such water for irrigation particularly in soils with poor internal [drainage systems](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/drainage-systems) that have inadequate leaching leads to only a part of the applied salt removed through deep drainage. The remaining salt in [irrigation water](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/irrigation-water) accumulates in the soil over a period of time. In soils with sufficient [internal drainage](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/internal-drainage) and areas with annual rainfall of more than 1000 mm, irrigation-induced soil salinization is very slow (FAO, 2003).

The accumulation of soluble salts in soil occurs when evaporation exceeds precipitation and salts are not leached but remain in the upper soil layers in low-lying areas. Natural soil salinization, referred to as “primary salinization,” occurs in arid and semi-arid [climatic zones](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/climatic-zone). [Salinization](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/salinization) of soil results from a combination of evaporation, salt precipitation and dissolution, salt transport, and ion exchange. Excessive salinity in soil leads to toxicity in crops, reduction in soil fertility, and reduction in availability of water to plants by reducing the osmostic potential of the soil solution, and a significant change in the hydraulic properties of soil. Irrigation with marginal water with a high content of soluble salts directly affects soil salinity (Sparks, 1995).

In shallow groundwater conditions, water and dissolved salts move by capillary action to the soil surface. When the water evaporates from the surface, the salts are left behind in the vicinity of roots rhizosphere (secondary salinization). The salts prevent plant roots from making use of water in the soil. Plant roots absorb water from the soil through the process of [osmosis](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/osmosis). Osmosis moves water from an area of lower salt (higher water) concentration to an area of higher salt concentration through semi- permeable memberane. The salt concentration inside a normal plant cell is about 1.5%, so that water moves into root cells. In [saline soils](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/saline-soil), the concentration of salt in the soil water can rise above 1.5% and prevent osmosis from moving water into the roots. It may cause water to move out of the root, thereby dehydrating the plant (Poljakoff-Mayber and Gale, 1975).

Soil salinization is often associated with [sodic soil](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sodic-soil). Natural or anthropogenic accumulation of sodium in the system leads to gradual replacement of [divalent](https://www.sciencedirect.com/topics/chemistry/monoatomic-dication) [cations](https://www.sciencedirect.com/topics/chemistry/monoatomic-dication) with Na+ on the exchange complex of clay minerals. The increased level of adsorbed Na+ causes the soil to become dispersed, which significantly reduces the [soil](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/soil-porosity) [porosity](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/soil-porosity) and permeability. This is a major problem for drainage of [soil water and](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/soil-salts) [salt](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/soil-salts) flush in the unsaturated zone. The predominance of Na+ in the exchanger phases occurs due to both high level of Na+ in the soil water and Ca2+ and Mg2+ precipitating as [calcium carbonate](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/calcium-carbonate) and calcium [sulfate](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sulphate) minerals. Sodic soils also develop under irrigation of water with higher sodium concentration, which requires special reclamation measures such as using [gypsum](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/gypsum) or CaCl2 salts to remove the exchangeable Na+ (Bresler *et al.*, 1982).

# Table 19. Detrimental Effects of Soil Salinity and Sodicity

|  |  |
| --- | --- |
| **Soil Salinity** | **Soil Sodicity** |
| Excess neutral soluble salt (chlorides and sulphates of Na, Ca and Mg) concentration lowers the osmotic potential of water, resulting in decreased availability of water to roots and thus exposes plants to secondary osmotic stress. This implies that all the physiological responses associated with the drought stress can also be invoked  by salt stress. | Excess alkali insoluble salts of sodium (Na+) thorough irrigation water causes dispersion of clays in fine textured soil. |
| Due to tightly held Ca2+ and Mg2+ on clay colloids in fine textured soil decreases zeta potential causing reduction in thickness of double diffuse layer which ultimately enhances flocculation | As Na+ is a monovalent which adsorbs on clay and enhances the zeta potential thereby stability of the clay takes place which increases the thickness of double diffuse layer which ultimately enhances dispersion or de-flocculation takes place and soil  structure is disturbed |
| This also prevents the absorption of water as well as nutrients. Excess soluble salts also causes the toxic effects on plants.  Excess soluble salts like NaCl and NaSO4 produces white saline soils while brown saline soils are also formed with higher concentration of NaNO3 | Soil dispersion causes clay particles to plug soil pores, resulting in reduced soil permeability. When soil is repeatedly wetted and dried and clay dispersion occurs, it then reforms and solidifies into almost cement-like soil with little or no structure. The three main problems caused by sodium-induced  dispersion are reduced infiltration, reduced |

|  |  |
| --- | --- |
|  | hydraulic conductivity, and surface crusting. |
| These soils under saline irrigation water are usually barren but productive. Germination, tillering, flowering, fruiting and overall growth of the plants is restricted. | **Infiltration:**  Soil dispersion hardens soil and blocks water infiltration, making it difficult for plants to establish and grow. The major implications associated with decreased infiltration due to sodium-induced dispersion include reduced plant available water and increased runoff and soil erosion. |
| Further excess soluble salts has an secondary salinization particularly in arid- semi-arid region thereby root growth and proliferation also restricted | **Hydraulic Conductivity:**  When sodium-induced soil dispersion causes loss of soil structure, the hydraulic conductivity is also reduced. If water cannot pass through the soil, then the upper layer can become swollen and water logged. This results in anaerobic soils which can reduce or prevent plant growth and decrease organic matter decomposition rates. The decrease in decomposition causes soils to become  infertile, black alkali soils. |
| Reduced microbial population and low soil microbial activity due to osmotic stress and toxic ions | **Surface Crusting:**  When clay particles disperse within soil water, they plug macropores in surface soil by two means. First, they block avenues for water and roots to move through the soil. Second, they form a cement like surface layer when the soil dries. The hardened upper layer, or surface crust, restricts water infiltration and plant emergence. |
| Soil nutrient availability is less thereby 25% more dose is generally recommended | Surface sealing of maro and micro pores  causes…   1. Soil aeration affected and anaerobic condition is formed 2. Decomposition process inhibited which causes decrease in nutrient transformations in soil 3. Less Microbial population and activity 4. Soil compactness enhances 5. Stagnation of water |
| These soil are aggregated and highly permeable and drainage is also good | Germination, root penetration and growth restricted, tillering, flowering fruiting get  reduced. |
| Generally deficiency of P, Zn, Fe and Mn  occurs in these soils. | Generally deficiency of N, P, Ca, Zn, Fe and  Mn occurs in these soils. |

**Management of Irrigation Water**

In order to determine the suitability of specific water for irrigation purpose, it is necessary to know not only its composition, but also the exact conditions of its proposed use as per soil type, climate and crops etc., the method of irrigation, and other management practices followed. Therefore, broad guidelines for assessing the suitability of irrigation water have been suggested from time to time for average use conditions. The following guidelines for utilizing poor-quality water or saline water and their wider applicability in different agro-ecological zones in India. To meet site-specific water-quality objectives, factors such as water-quality parameters, soil texture, crop tolerances and rainfall have all been considered.

* Use of gypsum for saline water having SAR > 20 and/or Mg:Ca > 3 and rich in silica.
* Fallowing during the rainy season when SAR > 20 and high-salinity water is being used in low-rainfall areas;
* Additional phosphorous application, especially when the Cl:SO4, ratio is > 2.0;
* Use of canal water at early growth stages, including pre-sowing irrigation.
* Using 20% extra seed and irrigating very soon after sowing (within 2-3 days) to improve germination
* Irrigation with saline water just before the onset of the monsoon will lower the soil salinity and raise the soil moisture, resulting in greater salt removal by the rains
* Use of organic materials in a saline environment to improve crop yields;
* Soils having either a shallow water table (within 1.5 m for a crop sown just before the monsoon) or hard subsoil layers, the next lower EC, and/or alternate types of irrigation (canal/saline) are applicable.

|  |  |
| --- | --- |
| **Cultural methods for salinity control measures** | |
| * Ploughing and levelling of land which increases infiltration and percolation rate * Providing proper drinage   + Artificial drins   + Tile drains   + Underground drinage * Use of subsoiler * Use of salt free irrigation water * Use of acidic fertilizers * Proper use of irrigation water * Use of organic manures: FYM/vermicompost * Mulching: Retardation of evaporation of water from soil surface * Green manuring * Salt tolerant crops (table 20) | * Dilution or alternate use of saline water * Deionizer and filteration * Testing of irrigation water * If na is high then gypsum can be used * Minimum use of saline water * Possibly used in light textured soils   **Salinity management techniques**   * + Scrapping of salts surface soil layer   + Heavy flooding before sowing   + Subsurface drinage:   + Seed placement of water   + More frequent irrigation   + Pre-plant irrigation or pre-sowing irrigation   + Localized fertilizer application   + Mixing of fertilizers with organic manures Sanding |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 20.Salt tolerant crops** | | | | |
|  | **Tolerant** | **Semi-tolerant** | **Sensitive** |  |
| Sugar  beet | Sunflower | Apple |
| Onion | Potato | Pulses |
| Turnip | Tomato | Fig |
| Cabbage | Cotton | Orange |
| Lettuce | Wheat | Cherry |

**References**

Ayers R.S. (1977). Adapted from “Quality of Water for Irrigation.” Jour. of the Irrig. and Drain. Div., ASCE. Vol 103, No. IR2, June 1977, p. 140.

Ayers RS, Westcot DW (1985). Water quality for agriculture. FAO irrigation and drainage paper 29 Rev 1. Food and Agriculture Organization of the United Nations, Rome, Italy, 174 pp

Bauder TA, Waskom RM, Sutherland PL, Davis JG (2011). Irrigation water quality criteria. Colorado State University Extension Publication, Crop series/irrigation. Fact sheet no. 0.506, 4 pp

Bhumbla, D.R. and Abrol, I.P. 1972. Is your water suitable for irrigation? Indian Farming. 22(4): 15-17.

Central Soil Salinity Research Institute, Karnal, Haryana. https://cssri.res.in/*CSSRI,* Karnal, Haryana

[D.S.G.ThomasN.J.Middleton](https://www.sciencedirect.com/science/article/abs/pii/S0140196383710086#!) (1993) Salinization: new perspectives on a major desertification issue. [Journal of Arid Environments](https://www.sciencedirect.com/science/journal/01401963) [Volume 24, Issue](https://www.sciencedirect.com/science/journal/01401963/24/1) [1](https://www.sciencedirect.com/science/journal/01401963/24/1), January 1993, Pages 95-105 <https://doi.org/10.1006/jare.1993.1008>

[Dennis Wichelns](https://www.sciencedirect.com/science/article/abs/pii/S0921800999000336#!) (1999). Analysis: An economic model of waterlogging and salinization in arid regions. [Ecological Economics](https://www.sciencedirect.com/science/journal/09218009). [Volume 30, Issue 3](https://www.sciencedirect.com/science/journal/09218009/30/3), September 1999, Pages 475-491

Doneen LD (1964). Notes on water quality in agriculture. Published as a water science

and engineering paper 4001, Department of Water Science and Engineering, University of California, Davis

Doneen LD (1964). Notes on water quality in agriculture. Published as a water science and engineering paper 4001, Department of Water Science and Engineering, University of California, Davis

Eaton FM (1950). Significance of carbonates in irrigation waters. Soil Sci 69:123–133 EPA; United States Environmental Protection Agency (U.S. EPA) (1986). Quality

criteria for water 1986, 1 May 1986, EPA 440/5-86-001.

Food and Agriculture Organization (FAO): Water quality for agriculture:https://[www.fao.org](http://www.fao.org/)

Follett RH, Soltanpour PN (2002). Irrigation water quality criteria. Colorado State University Publication No. 0.506. [https://doi.org/10.1016/S0921-](https://doi.org/10.1016/S0921-8009(99)00033-6) [8009(99)00033-6](https://doi.org/10.1016/S0921-8009(99)00033-6)

Kelly WP (1940). Permissible composition and concentration of irrigated waters. In: Proceedings of the A.S.C.F, 607.

Khodapanah L, Sulaiman WNA, Khodapanah DN (2009). Groundwater quality assessment for different purposes in Eshtehard District, Tehran, Iran. Eur J Sci Res 36(4):543–553

Kim J. and Sultan M. (2002). Assessment of long-term hydrologic impacts of Lake Nasser and related irrigation projects in southwestern Egypt. J. Hydrol. 262, 68–83.

Ludwick AE, Campbell KB, Johnson RD, McClain LJ, Millaway RM, Purcell SL, Phillips IL, Rush DW, Waters JA (eds) (1990). Water and plant growth. In: Western Fertilizer Handbook – horticulture Edition, Interstate Publishers Inc, Illinois, pp 15–43

P.S. Minhas (1996) Agricultural water management: Review for Saline water Management for irrigation in India. Central Soil Salinity Research Institute, Karma1 132001, India

Paliwal KV (1967). Effect of gypsum application on the quality of irrigation water.

Madras Agric J 59:646–647

Ramesh K, Elango L (2012). Groundwater quality and its suitability for domestic and agricultural use in Tondiar River Basin, Tamil Nadu, India. Environ Monit Assess 184(6):3887–3899

Saleh A, Srinivasula SM, Acharya S, Fishel R, Alnemri ES (1999). Cytochrome C and dATP-mediated oligomerization of apaf-1 is a prerequisite for procaspase- 9 activation. J Biol Chem 274:17941–17945

Scofield, C.S. (1936). The salinity of irrigation water. Smithsn Inst.Annual Report.

275-287.

Somwanshi, R.B, Kadu, P.P.Tamboli, B.D.,Patil Y.M and B.D. Bharare (1984). Analysis of plants, irrigation water and soils. STCRC, Department of Soil Science and Agricultura;l Chemistry, MPKV, Rahuri pp:1-245

Sumner, M.E.; Naidu, R. (1998) Sodic Soils Distribution, Properties, Management, and Environmental Consequences; Oxford University Press: New York, NY, USA.

Szabolcs I, Darab C (1964). Influence of irrigation water of high sodium carbonate content of soils. In: Proceedings of 8th international congress of ISSS, Transaction II, pp 803–881

Richard R.L. (1954). Diagnosis and improvement of saline and alkali soils. USDA Handbook No 60. Washington DC, USA 160 pp

Wilcox LV, Blair GY, Bower CA (1954). Effect of bicarbonate on suitability of water for irrigation. Soil Sci 77:259–266

London, F.M.1984. Brooker tropical soil manual, Longman Inc. New York.