# Brackish Groundwater Resource and Its Potential for Utilization in Irrigated Agriculture for Water Security in India[1]


## Synopsis

The amount of fresh or potable groundwater in storage has declined for many areas in the country and has led to concerns about the future availability of water for drinking-water, agricultural, industrial, and environmental needs. Use of brackish groundwater particularly in the irrigation sector, could supplement or, in some places, replace the use of freshwater sources and enhance our Nation's water security. However, a better understanding of the location and character of brackish groundwater is needed to expand development of the resource and provide a scientific basis for making policy decisions. In many parts of the country, groundwater withdrawals exceed recharge rates and have caused groundwater-level declines, reductions to the volume of groundwater in storage and decreased stream-flows. It is expected that the demand for groundwater will continue to increase because of population growth, especially in the arid west and north western part of the country. Further, surface-water resources are fully appropriated in arid and semi-arid regions of the country, creating additional groundwater demand. Development of brackish groundwater as an alternative water source can help address concerns about the future availability of water and contribute to the food security of the Nation. Further, advances of technologies are making treatment and use of brackish groundwater for irrigation, potable water supply and industrial use, more feasible. Brackish groundwater is potentially abundant. Early assessments indicated that brackish groundwater underlies large areas in Punjab, Haryana, Rajasthan, Uttar Pradesh, Karnataka and Tamil Nadu states in the country. Despite the need for alternative water sources and the potential availability of brackish groundwater, the most recent assessment was carried out by CGWB on national scale for the brackish /saline groundwater in 1997. An updated evaluation is needed to take advantage of newer data that have been collected over the last 20 years. In addition, consistent information about chemical characteristics (such as major-ion concentrations) and hydrogeological characteristics (such as aquifer material, depth, residence time, thickness, flow patterns, recharge rates, and hydraulic properties) of brackish groundwater has not been compiled at the national scale. Improved characterization is important for understanding and predicting occurrences in areas with few data and for assessing limitations imposed by different uses and (or) treatment options. This information is needed to understand the potential to expand development of the brackish groundwater resource and to provide a scientific basis for making policy decisions. Additional study will be needed to assess the potential of using brackish- and saline-water resources to supplement existing freshwater supplies for irrigation and domestic use. The present paper describes the characterization of brackish ground water in India, present use pattern and advances made in for use of brackish ground water with appropriate management techniques including amendments for irrigation water supplies without substantially affecting the crop yields.


Keywords: Brackish, supplement, amendments, management, crop yields.

## 1. Introduction

India receives a total of 4000 bcm of annual rainfall which flows through its rivers. Of this, about 28% (1123 bcm) is available due to topographical, hydrological and other constraints. The estimates of utilizable water and consumption are given in Table 1.

[1] Dr. R.C. Jain, Formerly Chairman, Central Ground Water Board & Central Ground Water Authority, India

Table 1. Water Budget-India

| | | |
|---|---|---|
| Estimated annual precipitation (including rainfall) | 4000 bcm | 100% |
| Average annual natural flow in rivers and aquifers | 1869 bcm | 46.5% |
| Estimated Utilisable water | 1123 bcm | 28.1% |
| i. Surface water (Rivers,lakes,ponds,streams) | 690 bcm | 60.15% |
| ii. Replenishable Ground water | 433 bcm | 38.5% |
| Total water consumption (Estimated 2010) | 702 bcm | 62.5% |
| i. Domestic | 42 bcm | 6% |
| ii. Agriculture/Irrigation | 550 bcm | 78.3% |
| iii. Industry | 56 bcm | 8% |
| iv. Environment, Navigation & Evaporation | 54 bcm | 7.7% |

Prima facie, this situation looks comfortable as current consumption is about 62.5% of total utilizable water. However, the scenario does not remain consistent across seasons and geography of the country. The geographical distribution of monsoon is highly uneven across the country with eastern parts receiving almost four times the annual precipitation than the western region. Monsoon season which is for period of three to four months (usually June- September), accounts for 75% of total annual rainfall. With limited systems for retaining this water locally or centrally for it to be used for the dry season, availability of water becomes a concern. This makes ground water an important component of the water budget, which serves country's water needs for a major part of the year. This excessive dependency on ground water resource has led to its over-exploitation.

The annual replenishable ground water resources comprise of 31.35% (447 bcm) of total utilizable water. According to CGWB almost 2064 assessment units of total of 6584 units have been categorized as either over-exploited, critical, semi-critical or saline. Out of the net ground water availability of 411 bcm, about 62% (253 bcm) is already withdrawn for agriculture, domestic and industrial uses.

At the current standards of living and economic activity in the country, the estimated water consumption is about 700 bcm (62.5% of utilizable water). As the economy grows water requirement for each of the sectors (as given in Table 2) would increase. It is estimated that total water demand for all the sectors will be higher than the total utilizable water in 2050.

Table 2. Total water requirement for different uses

| Sl. No. | Sector | 2010 | | 2025 | | 2050 | |
|---|---|---|---|---|---|---|---|
| | | Low | High | Low | High | Low | High |
| 1. | Irrigation | 543 | 557 | 561 | 611 | 628 | 807 |
| 2. | Domestic | 42 | 43 | 55 | 62 | 90 | 111 |
| 3. | Industries | 37 | 37 | 67 | 67 | 81 | 81 |
| 4. | Power | 18 | 19 | 31 | 33 | 63 | 70 |
| 5. | Inland Navigation | 7 | 7 | 10 | 10 | 15 | 15 |
| 6. | Environment -Ecology | 5 | 5 | 10 | 10 | 20 | 20 |
| 7. | Evaporation | 42 | 42 | 50 | 50 | 76 | 76 |
| | TOTAL | 694 | 710 | 784 | 843 | 973 | 1180 |

Source: Water & Related statistics 2015, CWC

Agriculture remains the top consumer of water resources in India and accounts for about 78% of total consumption. However, the net irrigated area is still at a low of 60 Mha as compared to Ultimate Irrigation Potential of 140 Mha.

Agriculture is also expected to see growth of 45% in water demand till 2050.This high demand for water is also an opportunity to focus on use of brackish water to supplement/replace use of limited fresh water resources, in addition to efficiency improvement to increase the irrigated area.

In addition, for meeting the increased domestic and industrial demand, the possibility of utilizing the brackish water resources, with appropriate management techniques need to be considered on priority to relieve the pressure of limited fresh water resources.

## Brackish Ground Water Resources

The ground water surveys in India indicate that different states use poor quality water in the range of 32 to 84% of the total ground water development. Groundwater of arid regions is largely saline and in semi-arid regions it is sodic in nature. These groundwater resources are used solely or in conjunction with canal water for irrigation purpose. Indiscriminate use of the poor-quality waters for irrigation deteriorates productivity of soils through salinity, sodicity and toxic effects. In addition to reduced productivity, it deteriorates the quality of produce and also limits the choice of cultivable crops. No systematic attempts have been made so far in the country to arrive at the estimate of poor-quality ground water resources. However, some predictions about use of poor-quality water in various states are given in Table 3. It is approximated that the total area underlain with the saline ground water (EC>4 dS m-1) is 193438 km2 with the annual replenishable recharge of 11765 million m3 Yr-1, leaving aside minor patches (CGWB, 1997).

Table 3. Use of Poor-quality groundwater in different states

| State | Utilizable groundwater | Net draft | Ground-water Development (%) | Poor quality water use (M ha-m $Yr^{-1}$) | Saline ground-water area >4 dSm-1 ($km^2$) (M ha-m $Yr^{-1}$) |
|---|---|---|---|---|---|
| | (M ha-m $Yr^{-1}$) | | | | |
| Punjab | 1.47 | 1.67 | 98 | 0.68 | 3058 |
| Haryana | 0.86 | 0.72 | 76 | 0.47 | 11438 |
| Uttar Pradesh | 6.31 | 2.98 | 42 | 1.42 | 1362 |
| Rajasthan | 0.95 | 0.77 | 73 | 0.65 | 141036 |
| Bihar | 2.06 | 0.82 | 36 | NA | NA |
| W. Bengal | 1.77 | 0.63 | 32 | NA | NA |
| Delhi | 0.01 | 0.01 | 120 | NA | 140 |
| Gujarat | 1.56 | 0.85 | 49 | 0.26 | 24300 |
| Karnataka | 1.24 | 0.45 | 33 | 0.17 | 8804 |
| Tamil Nadu | 2.02 | 1.40 | 63 | NA | 3300 |
| Madhya Pradesh | 2.66 | 0.73 | 25 | 0.20 | NA |
| Maharashtra | 2.29 | 0.88 | 35 | NA | NA |
| Andhra Pradesh | 2.70 | 0.78 | 26 | 0.25 | NA |
| India | 32.63 | 13.50 | 37 | | 193438 |

(Source: Minhas et al., 2004)

Poor quality alkali water zones occur in parts of Agra, Mathura, Aligarh, Mainpuri, Etah, Ballia and several districts of U.P. and parts of Haryana, Punjab and Rajastan. Low to medium RSC waters occupy about 47% area of Punjab. Highly alkali waters are found in Parts of Amritsar, Southern Ludhiana, Ropar, Patiala, Ferozpur, Bhatinda, Faridkot and Sangrur districts covering 25% of total area of the state. In Haryana alkali waters are found in Bhiwani, Mahendragarh, Gurgaon, Kaithal, Kurukshetra, Ambala, Karnal and Panipat districts covering almost 21% of the total area of the state. Saline area occupies another 36% area in Haryana. In parts of Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu poor quality sodic and saline waters are observed in the pockets. Many of these areas have black cotton soils. In east coast, areas between Krishna and Godavari rivers have brackish ground water. In coastal areas of Sunderban Delta, the ground water is saline. Scientific use of these waters enhances availability of water resources for irrigation as well as reduces negative impacts on soil and agricultural produce.\

## Classification of Irrigation Waters

Irrigation water is classified based on electrical conductivity (EC), sodium adsorption ration (SAR) and residual sodium carbonate (RSC). However, from management point of view, the groundwater in different agro-ecological regions can be grouped into three classes *i.e.* (a) good, (b) saline and (c) alkali / sodic. Depending on the degree of restriction, each of the two poor quality water classes has been further grouped into three homogenous subgroups (Table 4).

Table 4. Classification of poor-quality ground water

| Water Quality | ECiw (dS m$^{-1}$) | SARiw (mmol$^{-1}$) ½ | RSC (meq l$^{-1}$) |
|---|---|---|---|
| a. Good | <2 | <10 | <2.5 |
| b. Saline | | | |
| i. Marginally saline | 2-4 | < 10 | <2.5 |
| ii. Saline | >4 | < 10 | <2.5 |
| iii. High-SAR saline | >4 | >10 | <2.5 |
| c. Alkali waters | | | |
| i. Marginal alkali | <4 | <10 | 2.5-4.0 |
| ii. Alkali | <4 | <10 | >4.0 |
| iii. Highly alkali | Variable | >10 | >4.0 |

## Water Quality Guidelines for Management of Saline Ground water

It has been established that the success with poor quality water irrigation can only be achieved if factors such as rainfall, climate, depth to water table and water quality, soils and crops are integrated with appropriate crop and irrigation management practices. The available management options mainly include the irrigation, crop, chemical and other cultural practices but there seems to be no single management measure to control salinity and sodicity of irrigated soil, but several practices interact and should be considered in an integrated manner. The guidelines for use of saline ground waters are given below (Table 5).

Table 5. Guidelines for use of saline water (RSC < 2.5 meq/1)

| Soil texture (% clay) | Crop tolerance | Upper limits of ECiw (dS/m) in rainfall regions | | |
|---|---|---|---|---|
| | | 350 mm | 350-550 mm | 550-750 mm |
| Fine (> 30) | S | 1.0 | 1.0 | 1.5 |
| | ST | 1.5 | 2.0 | 3.0 |
| | T | 2.0 | 3.0 | 4.5 |
| Moderately Fine (20-30) | S | 1.5 | 2.0 | 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 |

S, ST and T denote sensitive, semi-tolerant and tolerant crops.

## Management Technologies for Use of Saline Ground water

Some of management options have been described as below.

- Selection of semi-tolerant to tolerant crops and crops with low water requirements
- Use of crop cultivars having tolerance to salinity (Table 6)
- Proper selection of crop sequence
- Avoiding saline water use during initial growth stages

Table 6. Promising cultivars for saline environment

| Crop | Cultivars |
|---|---|
| Wheat | Raj 2325, Raj 2560, Raj 3077, WH 157 |
| P. millet | MH269, 331, 427, HHB-60 |
| Mustard | CS416, CS330,-1, Pusa Bold |
| Cotton | DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9 |
| Safflower | HUS 305, A-1, Bhima |
| Sorghum | SPV-475, 881, 678, 669, CSH 11 |
| Barley | Ratna, RL345, RD103, 137, K169 |

## Nutrient management for saline environment

- Additional doses of nitrogenous fertilizers are recommended to compensate for volatilization losses occurring under saline environments

- Soils irrigated with chloride rich waters respond to higher phosphate application, because the chloride ions reduce availability of soil phosphorus to plants. The requirement of the crop for phosphoric fertilizers is, therefore, enhanced and nearly
- 50 per cent more phosphorus than the recommended dose under normal conditions should be added, provided the soil tests low in available P.
- For sulphate rich waters, no additional application of phosphate fertilizers is required and the dose recommended under normal conditions may be applied.
- For micro-nutrients such as zinc, the recommended doses based on soil test values should be applied.
- Farmyard manure (FYM): FYM and other organic materials have not only the nutritive value, but play an important role in structural improvements, which further influences leaching of salts and reduce their accumulation in the root zone. The other advantages of these materials in saline water irrigated soils are in terms of reducing the volatilization losses and enhancing nitrogen-use efficiency and the retention of nutrients in organic forms for longer periods also guards against their leaching and other losses. Therefore, the addition of FYM and other organic / green manure should be made to the maximum possible extent.

## Conjunctive Use of Canal and Saline Groundwater

In saline groundwater areas, conjunctive use practice can ensure judicious use of canal water, which is available in limited quantities along with saline ground water. Under such situation, two options are available with the users. Dilution or mixing of available poor-quality water with good water in such proportions that resultant EC is acceptable for the range of crops to be grown in a given area. The salinity of resulting water can be easily calculated from their respective volumes and salinities.

The management options for use of saline groundwater for irrigation, mentioned in the earlier section, are also applicable for conjunctive use of canal and saline water to maintain the productivity levels. If canal water (CW) is available during initial crop growth stages, maximum possible irrigations are to be given by canal water before switching to saline water (SW). Suppose wheat crop requires 4 irrigations. The 2CW: 2SW mode can be a good option as root zone salinity under this mode remains low for almost two months (during initial crop growing period). Then CW: SW alternate mode ensures low salinity for initial month. The mix (1:1) mode might be preferable over SW: CW option. It is obvious that 2SW: 2CW would get the least preference. Though the amount of salt load added under different conjunctive use modes is same, temporal changes in root zone salinity are different. Therefore, selection of proper mode of conjunctive use is required for suitable salinity management at the root zone for optimum crop yields. The preference order for conjunctive water use for wheat crop requiring 4 irrigations can be 2CW: 2SW; CW: SW alternate mode; Mix (1CW:1SW) mode and SW: CW alternate mode (Kaledhonkar and Keshari, 2006). The relative yield of crop generally remains highest for 2CW: 2SW and lowest for SW: CW mode. This assumption is violated, in case there is high salinity at time of germination and crop stand gets affected due to salinity. The conjunctive use preference order prepared for use of canal and saline groundwater also holds true for conjunctive use canal and alkali groundwater. The relative yields under different conjunctive water use practices, with reference to canal water irrigation, are given in the Table 7.

Some important suggestions for management of conjunctive use practices are listed below:

- Analysis of saline water to evaluate its use potential
- Selection of crops / crop varieties that can produce satisfactory yields with saline water irrigation
- Selection of tree species / medicinal plants in adverse condition
- Pre-sowing irrigation by good quality water so that germination and seedling emergence is not affected
- Adequate leaching of accumulated salts
- Alternating the area / area switching i.e. irrigate the selected area with saline water for 3-4 years and then switch to next area
- Improved cultural and nutrient management practices

Table 7. Effect of various cyclic modes of post-plant irrigations with canal water and saline water on mean relative (%) yields of wheat and succeeding pearl millet and sorghum crops

| Mode of water application | Wheat | Pearl millet | Sorghum fodder |
|---|---|---|---|
| 4 CW | 100 | 100 | 100 |
| CW: SW (alternate) | 94.4 | 97.0 | 91.8 |
| SW: CW (alternate) | 91.3 | 95.5 | 91.1 |
| 2 CW + 2 SW | 94.3 | 96.4 | 92.8 |
| 2 SW + 2 CW | 88.2 | 94.9 | 91.1 |
| 1 CW + 3 SW | 83.6 | 91.9 | 87.2 |
| 4 SW | 73.7 | 85.0 | 78.7 |

CW - Canal water; SW - Saline water

## Water Quality Guidelines for Management of Sodic Ground water

Based on field experience and results from different saline and sodic water use experiments, CSSRI, Karnal in consultation with Scientist from HAU, Hisar and PAU, Ludhiana has prepared some guidelines for efficient utilization of sodic waters. These guidelines emphasize on long- term influence of water quality on crop production, soil conditions and farm management with assumption that all rainwater received in field is being conserved for leaching and de-adsorption of $Na^+$ from upper root zone (Table 8).

Table 8. Sodic Groundwaters with RSC > 2.5 meq L-1 and ECiw < 4.0dSm-1

| Soil texture (% clay) | Upper limits of SAR (m mol L-1)$^{1/2}$ | RSCmeq $L^{-1}$ | Remarks |
|---|---|---|---|
| Fine(>30) | 10 | 2.5-3.5 | Limits pertain to kharif fallow – rabi crop rotation when annual rainfall is 350 –550 mm |
| Moderately fine(20-30) | 10<br>3.5-5.0 | | When water has Na < 75%, Ca+Mg >25% or rainfall >550mm, the upper limit of RSC becomes safe |
| Moderately coarse (10-20) | 15 | 5.0-7.5 | For double cropping, RSC neutralization with gypsum is essential based on quantity of water used during rabi season. Grow low water requiring crops during kharif. |
| Coarse (<10) | 20 | 7.5-10.0 | |

## Special considerations

- Gypsum application is necessary for sensitive crops if saline water (SAR > 20 and
- / or Mg: Ca ratio > 3 and rich in silica) induces water stagnation in rainy season.
- Fallowing in rainy season under high salinity (SAR > 20) is helpful for low rainfall areas.
- Fertilization with additional phosphorus is beneficial especially when C1:$SO_4$ ratio in waters is > 2.0.
- Canal water should be used preferably at early growth stages including pre-sowing irrigation in conjunctive use mode.
- Putting 20% extra seed rate and a quick post-sowing irrigation (within 2-3 days) will help in better germination.

- Accumulation of B, F, $NO_3$, Fe, Si, Se and heavy metals beyond critical limits with irrigation is toxic.
- Expert advice prior to use of such water is essential.

Textural criteria should be applicable for all soil layers down to at least 1.5 m depth. In areas, where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used

## Management Technologies for Use of Sodic Ground water

Water quality researches over past few decades have enabled development of technological options to cope up with the problems of sodic water use. Possibilities have now emerged to safely use the water otherwise designated unfit. These options are as below:

- Selection of crops (Table 10.7) cropping patterns and crop varieties (Table 9) that produce satisfactory yields under the existing or predicted conditions of sodicity.
- Appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies to maintain a high level of soil moisture and low level of salts and exchangeable sodium in the rhizosphere.
- Use of land management practices to increase the uniformity of water distribution, infiltration and salt leaching besides the optimal use of chemical amendments like agricultural grade gypsum and acidic pyrite at proper time and mode of their application with judicious use of organic materials and chemical fertilizers. The gypsum can be directly applied before rice crop in soil top layer or can be used in gypsum bed for passing sodic groundwater.
- The other guidelines pertinent to selecting crops suitable for sodic waters are:
    - Fields should be kept fallow during *kharif* in low rainfall areas (< 400 mm) where good quality water is not available. However, only tolerant and semi-tolerant crops like barley, wheat and mustard should be grown during rabi.
    - Jowar-wheat, guar-wheat, pearl millet- wheat and cotton-wheat rotations can be successfully grown in areas having rainfall > 400 mm / annum provided that sowing of kharif crops is done with rain or good quality water and only 2 to 3 sodic water irrigations can be applied to kharif crops.
    - In rice-wheat belt of alluvial plains having rainfall 600 mm, rice-wheat, rice-mustard, sorghum mustard, and *dhaincha* (GM)- wheat rotations can be successfully practiced with gypsum application.
    - Sodic water should not be used for summer crops in the months of April to June.

Table 9. Relative tolerance to sodicity of soils

| ESP | Crops |
|---|---|
| 10-15 | Safflower, Mash, Peas, Lentil, Pigeon-pea, Urd-bean, Banana |
| 16-20 | Bengal gram, Soybean, Papaya, Maize, Citrus |
| 20-25 | Groundnut, Cowpea, Onion, Pearl-millet, Guava, Bel, Grapes |
| 25-30 | Linseed, Garlic, Guar, Palmarosa, Lemon grass, Sorghum, Cotton |
| 30-50 | Mustard, Wheat, Sunflower, Ber, Karonda, Phalsa, Vetiver, Sorghum, Berseem |
| 50-60 | Barley, Sesbania, Paragrass, Rhoades grass |
| 60-71 | Rice, Sugarbeat, Karnal grass |

Table 10. CSSRI recommended crop varieties for cultivation in sodic soils

| Crop | pH | Varieties |
|---|---|---|
| Rice | 9.8-10.2 | CSR 10 |
| | 9.4-9.8 | CSR 10, CSR 13, CSR23, CSR 27, CSR 30, CSR 36 |
| Wheat | 9.2 - 9.3 | KRL-1-4, KRL-19, WH 157, Raj. 3077 |
| Mustard | Up to 9.3 | Pusa bold, Varuna, Kranti, CS-52, CS-54, CS-56 |
| Barley | Up to 9.3 | CSB 1, CSB 2, CSB 3, DL 200, DL 348. Ratna, BH 97, AZAD |
| Chickpea | Up to 9.0 | Karnal chana 1 |

## Nutrient management for sodic environment

Since sodic waters cause a rise in soil pH that leads to greater nitrogen losses through volatilization and denitrification, extra nitrogen may have to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron is also low due to their precipitation as hydroxides and carbonates. Some other beneficial tips as regards fertilizer use are.

- Application of 25% extra nitrogen is needed as compared to the normal conditions.
- Zinc sulphate @ 25 kg ha should be added, particularly to the rabi crop.
- Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil values.
- Some sodic waters may be rich in nutrients like nitrogen, potassium and sulphur such waters should be analyzed and the fertilizer dose of concerned nutrient reduced accordingly as per their composition in such water.
- In case of irrigation by sodic waters, the conjunctive use strategy should either minimize the precipitation of calcium or maximize the dissolution of precipitated calcium. This is particularly relevant to the areas, where canal water supplies are either un-assured or less than required, and farmers often pump sodic groundwater for crop production. For the efficient use of waters of different qualities, good quality waters can be used for sensitive crops and sodic waters for tolerant crops.
- The most appropriate practice, however, can be the conjunctive use of these waters by:
  - (a) blending in supply network, making appropriate water quality available for each crop irrespective of soil conditions;
  - (b) alternate use of sodic and canal water according to availability and crop needs; and
  - (c) switching these water sources during the growing season according to critical stages of crop growth.

The blending of sodic water and canal water is done in such proportion so that final RSC is maintained below the threshold limit of the crop to be grown. The alternate use is preferable and has operational advantages. Effect of conjunctive use of sodic groundwater and canal water on soil properties and crop yields is given in Table 11.

## Policy Issues related to Sustainable Development of Saline and Sodic Water Resources

- Precise delineation & demarcation of poor water quality aquifers, and determination of aquifer parameters through exploratory drilling and testing for assessment to their potential.
- Selection of appropriate type of well construction material and pumps capable of working under saline/sodic /alkaline environment.
- Conservation the available fresh water resources and make the judicious use of fresh water along with saline/ sodic water

- Development of institutional support for participation, development and optimal utilization of poor-quality groundwaters
- Diversification of agriculture and Incentives for water saving and adoption of improved technologies
- Education of the farmers about water scarcity, judicious use of water and side effects / losses due to salinity / sodicity

Table 11. Effect of cyclic use of sodic and canal waters on soil properties and crop yields

| Water quality/ mode | Adj SAR* | pH | ESP | RIR | Average yield (Mg/ha) | |
|---|---|---|---|---|---|---|
| | | | | | Rice | Wheat |
| Canal water (CW) | 0.3 | 8.2 | 4 | 100 | 6.78 | 5.43 |
| Sodic water (SW) | 22.0 | 9.7 | 46 | 14 | 4.17 | 3.08 |
| 2CW-ISW | 8.9 | 8.8 | 13 | 72 | 6.67 | 5.22 |
| 1CW-ISW | 12.8 | 9.2 | 18 | 59 | 6.30 | 5.72 |
| 1CW-2SW | 18.5 | 9.3 | 22 | 34 | 5.72 | 4.85 |

After accounting for 828 and 434 cm of irrigation and rainwater, respectively; Compiled from Bajwa and Josan (1989)

## References

Central Ground Water Board, 1997.Inland ground water salinity in India.

Central Water Commission,2015. Water and Related statistics.

Chadha D.K. and Sinha Ray S.P., Inland Ground water salinity in India.

Bajwa, M.S and Josan, A.S. 1989. Prediction of sustained sodic irrigation effects on soil sodium saturation and crop yields. *Agricultural Water Management*. 16: 227-228.

Kaledhonkar, M.J and Keshari, A.K., 2006. Modelling the effects of saline water use in agriculture. Irrigation & Drainage, 55(2): 177-190.

Minhas P.S.,Gupta Raj K. ,1992.Quality of Irrigation water-Assessment and management. ICAR, New Delhi.

Minhas, P.S., Sharma, D.R. and Chauhan, C.P.S. 2004. Management of saline and alkali waters for irrigation. In Advances of Sodic Land Recommendation. p121- 62. *International Conference on Sustainable management of Sodic Lands held at Lucknow*. Feb, 9-14, 2004.