Managing Poor Quality Waters for Mitigation of Droughts

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The availability of fresh water in the world is finite, whereas the demand for it is continuously increasing. Looking at the natural global water cycle that yields an annual renewable water supply of about 7000 m³ per capita (Shiklomanov, 2000), it is evident that there is enough freshwater available every year to fulfill the needs of the present population of this planet. Over 97 percent of the world's water resources is in the oceans and seas, and is too salty for productive uses. Two-thirds of the remainder is locked up in ice caps, glaciers, permafrost, swamps and deep aquifers. About 108,000 cubic kilometers (km³) precipitate annually on the earth's surface, of which roughly 60 percent (61,000 km³) evaporates directly back into the atmosphere, leaving 47,000 km³ flowing toward the sea. At present, only 3,400 km³ are withdrawn for use among different countries of the world. However, in certain regions and countries the annual renewable supply of water is less than 500 m³ per capita (much below the threshold limit of 1600 m³). In addition, the availability of water varies greatly over time in these areas, which results in extreme events such as droughts. What this contrast illustrates is that most of the freshwater available is concentrated in specific regions, while other areas are water-deficient (Pimental *et al.*, 1999; Rijsberman, 2006).

Because freshwater resources and population densities are unevenly distributed worldwide, water demands already exceed supplies in the regions that contain more than 40 % of the world's population. Further, the datasets and maps published in recent years show that
more and more countries will become water stressed as a result of increased water scarcity (FAO, 2003). Considering the trends in water withdrawal under the present practices and policies, future projections suggest that by the year 2035, about 60% of the world’s population will have to cope with severe water deficits (Cosgrove and Rijsberman, 2000). Under the pressure of rapid population growth and economic development, the available resources of water are being developed and exploited at a fast rate, and the situation seriously underlines the need for taking up integrated plan for water resources development, conservation and utilization for every agro-ecological area, especially the drought prone areas where water availability is both low in quantity and generally poor in quality.

Agriculture is the largest single user of water, with about 75% of the world’s freshwater being currently used for irrigation. In some countries, including India and Afghanistan, agricultural use accounts for as much as 90% of the total available water (FAO, 2003, 2005). Given that the water productivity in agriculture continues to be low, that improvements are only being made very slowly, and that freshwater has always been an integral part of food production, it is obvious that huge amount of water will be required to produce enough food for the future. In addition, increasing urbanization and populations in the water-deficit countries escalate the demand for freshwater. This results in competition among different water-user sectors and often, less freshwater being allocated to agriculture. The phenomenon of agriculture sector yielding part of its share of the available freshwater is expected to intensify in those less developed, arid and semi-arid drought prone countries and regions that are already suffering from water, food, sanitation and health problems (Qadir et al., 2007).

Non-conventional or poor quality water resources offer complementary supplies that can be used to partially alleviate water scarcity in the regions where renewable water resources are extremely scarce. Such water resources are harnessed for agricultural and other uses through specialized processes such as desalination of seawater and highly brackish water; collection, treatment and use of wastewater, capture and reuse of agricultural drainage water, and extraction of groundwater containing a variety of salts. Appropriate strategies shall be required when these waters are used for irrigation and meeting other requirements (Qadir and Oster, 2004; Sharma and Minhas, 2005).
Strategies for the Use of Poor Quality Waters

Large parts of Australia, the Indian sub-continent, China, countries in the Middle East and several regions in North Africa are generally water deficient, and the situation may further aggravate due to enhanced biotic pressure. Areas characterized by water scarcity are also usually underlain by aquifers of poor quality (Sharma, 2006). Nevertheless, driven by the pressure to produce more, even the brackish groundwater is being increasingly diverted to irrigated agriculture. For example, India's net annual net groundwater draft is 135 BCM. Of this, 32 BCM is estimated to consist of saline and/or sodic waters, which constitute about one-fourth of the total volume of groundwater used in the country (Sharma, 2006). The areas underlain with saline groundwater with high aridity, high water table are in the vicinity of seawater as in the coastal areas, while the alkali waters exist generally in the areas with annual rainfall of 500-700 mm. Large amounts of drainage effluents of poor quality are expected to be produced in the areas covered with sub-surface/surface drainage system. Many more areas with good quality aquifers are endangered with contamination, as a consequence of excessive withdrawals of groundwater (Shah and Debroy, 2002).

Saline and Alkali Water Management

Saline water management includes those methods, systems and techniques of water conservation, remediation, development, application, use and removal that provide a socially and environmentally favourable level of water regime to the agricultural production system at the least economic cost (Hillel, 2000). Possibilities have now emerged to safely use waters otherwise designated unfit, if the characteristics of water, soil and intended usages are known. This has led to replacement of too conservative water quality standards with site-specific guidelines, where factors like soil texture, rainfall and crop tolerance have been given due consideration (Minhas and Gupta, 1992).

There are two major approaches for improving and sustaining productivity in a saline environment: modifying the environment to suit the plant and modifying the plant to suit the environment. Both these approaches have been used, either singly or in combination, but the former has been used more extensively because it facilitates the use of alternative production inputs. Conjunctive use, water table
management, rain water conservation in precisely leveled basins, and chemical amelioration of alkali water are some of the important practices to achieve these objectives. The available management options are mediated through the management of crops, irrigation water, chemical/amendment and cultural practices, but there seems to be no single management measure to control salinity and sodicity of such soils, but several practices interact with each other and should be considered in an integrated manner.

**On-farm irrigation management**

Under water scarcity conditions, direct application of saline water can be practiced where salinity of water is such that a crop can be grown within acceptable yield levels without adversely affecting soil health. The average yield reductions were less than 20% for crops like cotton, millet, mustard and wheat when waters with EC of 4-6 dS/m were used in the light textured soils of Haryana. Crops like sorghum and mustard could tolerate higher salinity once the non-saline water was substituted for pre-sowing irrigation to leach out the salts of the seeding zone. Such a substitution enhanced germination; crop growth and yields increased markedly and also resulted in better utilization of soil-water even from the lower soil layers during the drought conditions.

To augment the limited supplies of fresh water during drought conditions, the resource can be augmented through conjunctive use of saline and fresh water through its application in cyclic and blending mode. Blending is promising in areas where freshwater can be made available in adequate quantities on demand. The potential for blending two different supplies depends on the crops to be grown, salinities and quantities of the two water supplies, and the economically acceptable yield reductions. Cyclic use is most common and offers several advantages over blending. Analysis of a large number of studies showed that at the same level of salinity, the yields for different cyclic use modes were higher than the estimated yields for mixing (Minhas and Tyagi, 1998). For application of poor quality and limited water supplies under the drought conditions, drip irrigation can cover much larger areas and also enhance the threshold limits of the salt tolerance by modifying the patterns of salt distribution and maintenance of constantly higher matric potential. Drip system seems to be the best method of saline water application, as it avoids leaf injury to the plants that can occur with sprinkler irrigation (Table 1, Aggarwal and Khanna, 1983).
Table 1: Yield and water use efficiency of crops under different irrigation methods.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Average yield (t ha⁻¹) for irrigation method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface method</td>
</tr>
<tr>
<td></td>
<td>CW*</td>
</tr>
<tr>
<td>Wheat</td>
<td>4.00 (97)</td>
</tr>
<tr>
<td>Barley</td>
<td>3.51 (147)</td>
</tr>
<tr>
<td>Cotton</td>
<td>2.30</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>2.38</td>
</tr>
<tr>
<td>Drip method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface method</td>
</tr>
<tr>
<td>Radish</td>
<td>(ECw 6.5 dSm⁻¹)</td>
</tr>
<tr>
<td>Potato</td>
<td>(4 dSm⁻¹)</td>
</tr>
<tr>
<td>Tomato</td>
<td>(10 dSm⁻¹)</td>
</tr>
<tr>
<td>Tomato</td>
<td>(4 dS/m)</td>
</tr>
<tr>
<td></td>
<td>(8 dS/m)</td>
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</tbody>
</table>

*Figures in parenthesis denote water use efficiency (kg/ha-cm)
*CW = Canal Water, SW = Saline Water (ECw 12 dS/m)

Amelioration of alkali water

In case the drought occurs later during the season, irrigation with alkali water given after two turns of irrigation with fresh water helped in obtaining rice and wheat yields comparable to those with fresh water irrigation. In case, only alkali water is available as a source of irrigation, its quality can be ameliorated by passing the flow through gypsum beds (Pal and Poonia, 1979). The use of gypsum bed technique improves the solubility and application efficiency of gypsum. The gypsum bed may be constructed with brick-cement-concrete, the size of which primarily depends upon alkali water tubewell discharge. A net of iron bars covered with wire net (2 mm x 2 mm) is fitted at a height of 10-20 cm from the bottom of the chamber and this supports a bed of gypsum clods. This chamber is
connected to the waterfall chamber from the bottom, and the water after passing through the gypsum bed exits the bed into the irrigation channel. This method has considerable saving and produces higher crop yields.

**Alternate land use systems**

Land and water resource endowments are extremely poor in the drought prone areas. In the lands that are already degraded, it is neither feasible nor economical to put these under crop production. Best land use under such situations is to retire such areas to permanent vegetation. Conventional planting methods result in poor survival percentage under saline environments. To establish good plantations and to improve biomass production under such adverse environments, ‘SPFIM’ (Sub-surface Planting and Furrow Irrigation Method) system of planting has been devised (Tomar et al., 2002). In this method, saplings are planted in furrows and raised beds act as micro-catchments. This improved method not only saves irrigation time and labour but also leads to lesser salt accumulation in the soil profile. Irrigation is applied only to sapling-planted furrows covering one-fifth to one-tenth of the total area. Quantities of water equal to 10 % of the open pan evaporation, sufficed for optimal growth of several tree species under drought situations in the arid and semi-arid areas (Minhas et al., 1997). Preferred choices for tree species are; *Tamarix articulata*, *Prosopis juliflora*, *Acacia nilotica*, *Acacia tortilis*, *Fironia limonia*, *Acacia farnesiana*, and *Melia azadirach*.

Moreover, the degraded lands in the drought prone arid and semi-arid regions are traditionally left for pastures, but their forage productivity is low, unstable and nonremunerative. Usually, there are acute shortages of fodder under the drought conditions and need to be transported in large quantities from the non-affected areas. Alternatively, large herds and herdsmen migrate to the neighboring regions under severe hardships. When the limited saline ground water resources were utilized to supplement rain water supplies, the forage grasses like *Panicum laevifolium* followed by *P. maximum* (both local wild and cultivated) outperformed the other grasses (Tomar et al., 2003). Saline irrigation not only improved their productivity by 3-4 fold, but fodder (about 30 %) could also be made available during the scarcity periods of April-June, when most pastoral nomads are forced to move towards the adjoining irrigated areas in search of fodder (Sharma and Minhas, 2005). These brackish water based agro-forestry systems have also emerged as eco-friendly phyto-remediation crops for the degraded soils in drought prone areas (Qadir and Oster, 2002).
Desalination of Seawater

Seawater, due to its high salt content, cannot be used directly by the humans or animals and for crop production. Desalination, a process that converts seawater or highly brackish groundwater into good quality freshwater, has been practiced for over 50 years. The scarcity of freshwater has provided a driving force for the use of this approach in the arid and semi-arid regions and in countries bordering seas or salt lakes. The largest producers of freshwater from seawater are the arid Middle Eastern countries, though several other countries have a compelling need to desalinise seawater and highly brackish groundwater to produce freshwater. Currently, desalination plants operate in more than 120 countries worldwide (Voutchkov, 2004), and estimates show that desalination plants produce $30 \times 10^6$ m$^3$ of freshwater each day. This suggests that the total amount of freshwater produced each year from desalination is around $11 \times 10^9$ m$^3$.

The reverse osmosis plants have several advantages over distillation plants including a high recovery rate of over 45% in case of seawater. Over the years, the cost of desalination has decreased dramatically and the present costs vary between US$ 0.5 and 0.6 per cubic meter. Bearing in mind the costs of other conventional and non-conventional water resources, which could be used for agriculture, the use of desalinated water for traditional agricultural production systems remains an expensive option, although desalinated water is being used on a small-scale for high-tech and high-value agriculture in areas such as southeastern Spain. The costs of investments and operation are shared equally between the farmers and the government to overcome the recurrent droughts in this region of Spain. Since 1994, more than 90 reverse osmosis plants have been installed in this part of Spain with an annual production rate of $55 \times 10^6$ m$^3$ of desalinated water (Latorre, 2002).

Use of Marginal-quality Wastewater

Driven by rapid urbanization and improved living standards, greater amounts of wastewater are being produced worldwide. This is equally true for the drought prone areas located in the arid and semi-arid environments. In drier climates, the farmers often use the wastewater itself from the drains and sewers, because it is the only (reliable) source of water. Larger coverage of the towns and villages with water supply schemes ensures higher amounts of wastewater production because the depleted fraction of domestic and residential
water use is typically only 15-25%, with the remainder returning as wastewater. The use of urban wastewater in agriculture is a centuries-old practice that is receiving renewed attention with the increasing scarcity of freshwater resources in the water scarce regions.

Presently, about 15% of India’s water resources are consumed for domestic and industrial requirements, and share of these two sectors will grow to about 30% by 2050. Current status of wastewater quantities as documented by the Central Pollution Control Board of India (2000) is about 16,663 million liters per day. After treatment, and in conjunction with suitable management practices, this could be reused for a variety of purposes. Estimates of the extent to which wastewater is used for agriculture worldwide reveal that at least $2 \times 10^6$ ha are irrigated with treated, diluted, partly treated or untreated wastewater (Jimenez and Asano, 2004). The use of untreated wastewater is intense in the drought prone areas with no or little access to other sources of irrigation water. The wastewater is widely used as a low-cost alternative to conventional irrigation water; as it supports livelihoods and generates considerable value in the urban and peri-urban agriculture despite the health and environmental risks associated with this practice. Though pervasive, this practice is largely unregulated in low-income countries, and the costs and benefits are poorly understood.

There is now more scope in the water and environment sector to develop and implement wastewater treatment technologies that: (1) need low levels of capital investment for construction, operation and maintenance; (2) maximize the separation and recovery of byproducts from polluted substances; (3) are compatible with the intended reuse option in that they yield a product of an appropriate quality in adequate quantities; (4) can be applied at both very small and very large scales; and (5) are accepted by the farming communities and the local population. Bearing in mind that the treated wastewater could be used for agricultural, environmental, recreational and industrial purposes, especially in the drought prone areas; it is important to realize that such wastewater must be adequately treated and used appropriately (Qadir et al., 2007). Based on different parameters, various guidelines (Blumenthal et al., 2000; WHO, 1989 and 2006; (in press) are available for wastewater use in agriculture. However, most farmers in the developing countries use untreated wastewater in an unplanned manner to irrigate a variety of crops. The farmers consider such untreated wastewater to be a reliable source of irrigation water like groundwater pumping. Other benefits to the farmers
include the fact that farmers have to invest nothing, or very little, in fertilizer purchase and application while benefiting from greater levels of production of high value vegetables and cash crops.

Economic analysis based on the cost of production of different crops has shown attractive returns from wastewater-irrigated fields in Syria (Qadir et al., 2007). The analysis revealed that each US$ invested in production process gave a return of US$ 5.31 from wheat irrigated with wastewater and US$ 2.34 when irrigated by groundwater. The cultivation of vegetables with wastewater had the highest benefit-cost ratio of 7.48. In Pakistan, the wastewater farmers typically earn 30-40 percent more per year than the farmers using conventional irrigation water, while in Ghana, dry-season irrigation with wastewater allows an average extra income of 40-50 percent (IWMI WPB 17). The minimum degree of treatment necessary to eliminate the health risk and to grow suitable crops with different wastewaters, as suggested by Juwarkar (1991), are given in Table 2.

Wastewater irrigation of forest species grown for the non-edible products like fuel and timber can help in overcoming health hazards associated with sewage farming. Developing and maintaining green belts/shelterbelts in the drought prone areas with wastewater irrigation also helps revive ecological balance, and improves

<table>
<thead>
<tr>
<th>Treatment level</th>
<th>Type of crops</th>
<th>Crops in order of preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary treated</td>
<td>Cash crops</td>
<td>Cotton, jute, sugarcane, tobacco</td>
</tr>
<tr>
<td></td>
<td>Aromatic grasses</td>
<td>Citronella, mentha, lemon grass</td>
</tr>
<tr>
<td></td>
<td>Cereals and pulses</td>
<td>Wheat, rice, green gram, black gram, sorghum, pearl millet</td>
</tr>
<tr>
<td></td>
<td>Oil seeds</td>
<td>Linseed, sesame, castor, sunflower, soybean, groundnut</td>
</tr>
<tr>
<td></td>
<td>Fruit crops</td>
<td>Coconut, banana, citrus, sapota, guava, grapes, papaya, mango</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>Brinjal, beans, lady finger</td>
</tr>
<tr>
<td>Secondary treated</td>
<td></td>
<td>All crops as above and vegetables grown near the soil surface</td>
</tr>
<tr>
<td>Disinfected sewage</td>
<td></td>
<td>All crops without restriction</td>
</tr>
</tbody>
</table>
environmental quality by self-treatment of wastewater through land application and forest irrigation. Such systems convert nutrient energy into biomass, thereby bringing multiple benefits to the society such as fuel wood, timber, environmental sanitation and eco-restoration in the drought prone areas (Minhas and Samra, 2004). Additional advantage of tree plantations would be the harvest of large amount of toxic metals, as the trees are known to sequester, tolerate and accumulate higher levels of these toxic metals.

Studies carried out by the International Water Management Institute (IWMI) have proposed a number of options to minimize the risks involved in the use of untreated wastewater for agriculture (Scott et al., 2004). These options include:

- Use of suitable irrigation techniques and selection of appropriate crops that are less likely to transmit contaminants and pathogens to the consumers.
- Use of protective measures such as boots and gloves to minimize exposure of the farm workers to pathogens.
- Implementation of a medical care program through the use of preventive therapy such as anti-helminthic drugs.
- Post-harvest management of vegetables, through washing and improved storage.
- Conjunctive use of freshwater and wastewater to dilute the risks and increase the benefits by supplying nutrients to a large area.
- Upstream wastewater management and appropriate low-cost treatment.
- Education and increased awareness among the farmers, consumers, and government organizations.
- Implementation of monitoring programs for key environmental, health and food safety parameters.

Proper implementation of these options (and other measures outlined in the 'Hyderabad Declaration on Wastewater Use in Agriculture' http://www.iwmi.cgiar.org/home/wastewater.htm) can lead to a much safer use of this assured and increasing resource of wastewater for mitigation of droughts and improved livelihoods in the urban and peri-urban areas of the developing countries. An example of a decision-making process that can be used to identify
Poor Quality Waters for Mitigation of Droughts — Sharma

Is wastewater treatment possible?

No, or not satisfactory

Can alternative cropping areas and/or safer water sources be allocated and are they acceptable?

Yes

Apply microbiological guidelines for irrigation water

And

Improve farmers' awareness on pathogen transfer and provide for safer farming practices

And

Explore and Support
- On-farm water treatment
- Crop restrictions
- Safer irrigation methods

And

Make traders and authorities aware of the potential for post harvest contamination

And

Farm level

Market level

Consumer level

Teach improved food disinfection methods based on local customs

And

Increase consumers' demand for safe food and implement crop certification schemes

And

Provide access to clean water and sanitation facilities in markets

Future Perspectives

Intense competition for good quality water among the different water-user sectors is expected to reduce the amount of fresh water allocated to agriculture in the foreseeable future, and this competition is likely to be fierce in the water scarce drought prone areas. Increasing the productivity of water and making use of poor quality water in agriculture will play a vital role in easing this competition, in prevention of environmental degradation, and provision of food
security. As the situation currently stands, despite improvements in water-use efficiency techniques, water scarce regions are expected to become increasingly reliant on the non-conventional poor quality water resources and the other opportunities available to augment water supplies, thereby, achieving food security.

There is emerging evidence that the use of saline and/or sodic waters in conjunction with the adoption of appropriate soil, crop and irrigation management strategies can boost agricultural productivity and thus, mitigate the droughts far more efficiently than was previously thought. The future use of cyclic, blended, and/or sequential technologies for using these waters is expected to increase. These waters have also very high potential for establishment of the much-needed agro-forestry and pastureland uses in the drought prone areas for sustaining the high livestock population. This will also mitigate the distress caused by the large scale and frequent migration of herds and herdsmen during the drought periods, and minimize the need for transport of huge and emergent volumes of feedstock.

Currently, desalination of seawater and highly brackish groundwater provides 11 BCM of high quality water per year. Although it is generally believed that the costs involved in desalination will decrease, but not by an order of magnitude at any time in future as to be available for traditional agriculture. The states must either develop high-tech high-value agriculture (as in Spain and Israel) using minimal amounts of water under protected environment or identify/develop suitable germplasm of good economic value which can tolerate high levels of salinity.

**Conclusions**

Assured and increasing supplies of marginal-quality wastewater are valuable resources in water scarce countries. Given the water scarcity in the drought prone regions, the cost of treating wastewater in these countries could be more attractive than the option of developing new supplies for different water-user sectors. Wastewater can also be used to establish forestry plantations/shelterbelts in the dry areas for economic reasons and environmental restoration. Therefore, steps must be taken to maximize the benefits and minimize the risks involved in wastewater use in agriculture. There are several ‘bright spots’ in the drought prone areas where communities make increased and
effective use of non-conventional water resources through an integrated water resource management to mitigate the drought impacts. If strategies and technologies are developed using the accumulated wisdom of such communities, not only people’s participation will be enhanced but also new measures will be adopted.

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