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Perspectives on Political and Social Regional Stability Impacted by Global Crises - *A Social Science Context*

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Contributing Authors:
Clare Lockhart (State Effectiveness Institute), Philip Martin (UC-Davis), Jack A. Goldstone (GMU), Elizabeth Leahy Madsen (PAI), David L. Richards (Memphis), Ronald Gelleny (Akron), Peter Steen (JS/J-5), Jerome Delli Priscoli (USACE), J. Rolf Olsen (USACE), Kathleen D. White (USACE), Julie E. Kiang (USGS), D. Phil Turnipseed (USGS), Levi D. Brekke (Reclamation), David A. Raff (Reclamation), Roger S. Pulwarty (NOAA), Robert Webb (NOAA), Alex O.Dehgan (DOS), Laura Jean Palmer-Moloney (USACE), James Diaz (LSU), Kenneth S. Yalowitz (Dartmouth), Ross A. Virginia (Dartmouth), Richard J. Stoll (Rice), Douglas J. Arent (NREL), Jeffrey Steiner (USDA), Timothy Griffin (Tufts), Donald Suarez (USDA), Debarati Guha-Sapir(CRED), Daniel Strickman (USDA), Victor Asal (Albany), Stephen Shellman(William and Mary), Lawrence A. Kuznar (NSI), Laura Leets (NSI), J. Joseph Hewitt (CIDCM), Tom Rieger (Gallup), Frank C. Zagare (SUNY Buffalo), Robert Axelrod (Michigan), George Cybenko (Dartmouth), Douglas Madory (Dartmouth), Stephen M. Millett (Futuring Assoc), Ame Stormer (DMHA), Jessica Wambach (DMHA), and Lt Gen (Ret) John F. Goodman (DMHA), Robert Popp(NSI), Tom Mullen (PA)

Compiled by: Rosa Affleck (ERDC-NH) – Rosa.T.Affleck@usace.army.mil
Rose Rainey (IIA) – rraney@iiaweb.com
April Hartman (NSI) - ahartman@NSIteam.com
Deborah Pyle (SRC) – Deborah.pyle@js.pentagon.mil

2.5.B. Food Production in Arid Regions as Related to Salinity (Donald Suarez)

Author and Organizatin: Donald Suarez, Salinity Laboratory, Agricultural Research Service, US Department of Agriculture
Contact Information: Donald.Suarez@ars.usda.gov

Abstract

Arid and semiarid regions of the world are generally associated with high population density and lower–than-average per capita incomes and living standards. These regions are vulnerable to food shortages due to current, unsustainable use of fresh water for irrigation and increasing soil salinization. In many countries, current crop production cannot be sustained without adoption of new management practices and alternative water supplies. This paper discusses the issue of water supply, the impact of salinity, the potential for water reuse (both of irrigation drainage water and municipal waste water), the utilization of saline waters for crop production and the potential problems associated with the use of these alternative waters for irrigation.

Introduction

There has been a dramatic increase in total global food production, as well as an increase in food production on a per-acre basis, over the last 50 years. This increase is generally attributed to improved crop varieties and management practices (green revolution), however at least part of this increase is related to an increase in the amount of irrigated acreage. Irrigated lands have much higher productivity and economic return per acre as compared to non-irrigated lands. It is estimated that globally, irrigated lands represent 15% of the cultivated land, yet they produce over 30%[1] to 40%[2] of the world's food. The 35% increase in irrigated land from 1970 to the late 1980s thus provided a significant part of the increase in world food production, and was a major factor in avoiding large scale famine.

Since the 1980s, there has been a significant decline in the rate of growth in the world's irrigated land, with a leveling off of the total irrigated acreage in the first decade of this century. The reason for the leveling is due partially to the limitations of suitable land, but more importantly it is due to the lack of new developable water supplies in most of the arid and semiarid regions that can most benefit from irrigation. Globally, irrigated agriculture uses approximately ⅔ of the total water used, with industrial and municipal use making up the balance. Supplemental irrigation in more humid regions has increased, masking the decline in irrigation in arid regions. California, as an example, has experienced significant declines in irrigated acreage, some of which are considered temporary as a result of drought, while others are more permanent due to declining ground water supplies as well as increasing urban and environmental water demands.

Unfortunately, most arid regions do not have new developable surface waters and the large fresh water extractions of ground water required for irrigated agriculture cannot be increased. Of greater concern is the consideration that irrigation is not sustainable at current fresh water utilization rates. This over utilization of fresh water is particularly severe in drier regions of the world, where population density, poverty, and food demands are greatest. Over drafting of groundwater has resulted in declining water tables, loss of shallow fresh water for municipal use, and sea water intrusion in coastal regions. In early 1990s, approximately one fifth of the U.S.'s irrigated lands were extracting groundwater water in excess of the natural recharge.[3] The data are not completely known, but the situation appears more severe in many less developed nations.

Increasing population results in increasing total demand for fresh water for municipal and industrial use as well as for increased food production. Increased fresh water needs are also related to increased per capita water usage associated with improved economic conditions in a region. Increases in living standards are not only related to increased domestic per capita water consumption, but they also result in increased in water consumption related to food production on a per capita basis. This increased demand with improved living standards is related to the increased water requirement for meat production versus grain production (expressed as gallons of water per kcal). It will be a major challenge just to maintain the existing level of irrigation and associated food production in the arid and semiarid regions of the world. An increase in living standards will require yet more water.

Salinity

In addition to the unsustainable extraction of fresh water, there is a related decline in water quality of existing supplies. A substantial part of the increasing salinity of water supplies in arid regions is unavoidable when irrigating, unless the drainage water from irrigation is isolated from fresh water supplies. Salinity increases in drainage water relative to irrigation water are inevitable due to the fact that plants extract water and leave most of the salts behind, concentrating these salts in the remaining water. Typically, plants extract only 5–10% of the salt associated with the water that they extract. Hence, more efficient irrigation (generally resulting in less water applied more uniformly), while desirable, results in smaller volumes of drainage water, but of greater salinity. The salinity increase is approximately inversely proportional to the change in volume (inverse to volume of irrigation water/volume of drainage water).

It is estimated that over 20% of irrigated land in the U.S. is salt-affected.[4] Globally, it is estimated that ⅓ of all irrigated land (76 million hectares [Mha]) is salt affected as a result of human activity,[5] meaning that crop yields are reduced. Salinity is a major threat to current irrigation projects and to the remaining near-surface fresh water supplies in arid regions. The extent of the salinity problem has not stabilized; instead, it is estimated that as much as 2 Mha of irrigated land, representing 1% of the total, is lost from production due to salinity each year.[6]

Most of the salt affected lands are in Asia and Africa. In contrast to salinization of water supplies, soil salinization is more readily controlled. Most soil salinization has occurred as a result of over irrigation, resulting in drainage volumes to the subsurface in excess of natural drainage capabilities and subsequent water logging, evaporation of water, and deposition of salts at or near the soil surface. Ensuring that soils are not over irrigated and maximizing food production per unit of water applied requires changes in irrigation systems. For example, conversion of surface flooding or furrow to drip irrigation allows for more uniform application of water, reduced need for irrigation water and reduced drainage volumes. These system changes and associated changes in management practices require capital investments and education programs for irrigators.

Increased salinization in arid and semiarid regions is also caused by leaching of existing salts from the soil during irrigation in regions with high salt containing strata, as well as by application of waters of low quality without proper management. In the instance of soils high in native salts, regional salinization of ground and surface waters is aggravated by excessive water applications. This impact is particularly important when implementing a new irrigation project, but the impacts of leaching salts present before irrigation may be observed for in excess of 120 years after initiation of the irrigation project (Grand Valley, Colorado), depending on the hydrology of the system and the type of salts present. In this instance, improved water management is essential for salinity control and for maintenance of existing fresh water supplies. Improvements in irrigation system infrastructure and management in Grand valley Colorado, including concrete lining of canals and laterals, installation of closed pipe delivery systems, and irrigation scheduling has reduced the salt load to the Colorado River by approximately 500,000 tons per year.

Since saline water is not generally usable by agriculture with present technology, salinization of water resources represents a loss of useable water and can be a source of conflict among nations. Development of new irrigation projects upstream in a river basin inevitably results in adverse consequences to downstream users, either with reduced waters flows, increased salinity, or a combination of both.

Water Reuse

Municipal water demands throughout the world are high and increasing over time. These increases are greatest in the arid and semiarid regions, where the population growth is also greatest. However, municipal use cannot be considered a completely competitive use for fresh water. Only a fraction (typically 25%) of the water diverted for municipal use is actually consumed (by evaporation or plant transpiration). The majority of the municipal water is either degraded or lost due to leakage in the delivery system. Water currently lost via leakage is generally not available, as it may mix with saline or contaminated ground waters and thus be unusable, depending on local hydrologic conditions. Improvements in the municipal water delivery system can reduce the current all too common leakage of up to 50% of extracted water. These improvements, coupled with collection of wastewaters in a sewage system (with minimal losses in the system) can result in recovery of up to 70% of the allocated municipal water. It can thus be considered that municipal users primarily degrade rather than consume water. Increasing municipal demands for fresh water will result in corresponding increases in municipal wastewater.

In order to sustain agricultural productivity and irrigated acreage, especially in the arid and semiarid regions of the world, there will need to be a dramatic shift from fresh water to either treated wastewaters or alternative saline waters. Use of desalination for irrigation water does not yet appear economically viable, despite continuing advances in the technology and current increases in its use for drinking water. At present, costs are typically in the $1,000-per-acre-foot range when subsidies are fully considered,[7] and a large portion of the cost is associated with energy consumption. These high capital and production costs may be viable for a few very high value specialty crops in developed nations if there is no other water source, but it is not an option for production of basic food needs in less developed nations. Nonetheless, desalination is increasingly being used for municipal drinking supplies as it becomes cost effective with alternative supplies in arid coastal regions (such as in southern California and in Gulf states in the Middle East).

Marginal waters for irrigation contain (1) elevated concentrations of salts, typically above 2 dS/m in electrical conductivity, (2) elevated values of sodium adsorption ratio (SAR), which is defined as $Na/(Ca + Mg)^{0.5}$, where concentrations are expressed in terms of mmol/L (3) sometimes elevated pH, and (4) boron (B) concentrations that are potentially toxic to plants.

The adverse effects of SAR and elevated pH on hydraulic conductivity (soil property related to infiltration) when combined with low salinity are well documented.[8,9] Increased sodium levels relative to calcium (Ca) and magnesium (Mg) are associated with a loss of soil structure, clay migration, and reduction in water infiltration rates. These losses can be sufficient to cause severe and at times even total loss of soil productivity. Once the lands are degraded in this manner restoration of productivity is difficult and expensive, hence it is important to avoid degradation.

Current guidelines for irrigation[10] based on laboratory studies and field observation indicate that waters of SAR 10 or below can be used with no reduction in rate of infiltration when the salinity of the irrigation water is at or above 2 dS/m. On this basis, it has been assumed that most treated waste waters can be used without loss in infiltration. However, more recent research[11,12] indicates that over an irrigation season, losses in infiltration are significant even at lower SAR (SAR 4-6) and that for systems using both rainfall and irrigation (the general situation for irrigated regions), any increase in SAR reduces the infiltration rate.

A reduction in the soil infiltration rate is undesirable for several reasons. Reduced infiltration rates result in greater time to infiltrate irrigation water, causing water ponding on the surface and possibly insufficient water infiltration to meet crop water needs. It may also result in generation of oxygen deficient soil conditions, all with adverse crop effect on crop production. Perhaps most importantly, a reduction in infiltration rate will result in decreased infiltration of rainfall, increased runoff, and increased soil erosion. In many irrigated regions rainfall is limited but especially winter rains are an important component of the irrigation system, enabling leaching of salts from the soil during and enabling a non saline environment for seedling development in the spring.

In addition to a decrease in the water infiltration rate, loss of infiltration will result in a loss in recharge from rain events. This is very adverse in irrigated regions that are using low quality waters since the rain is often a major component of leaching. A good example is the leaching of salts from the soil profile in the Mediterranean region due to winter rains. Rains during the pre-plant time are especially valuable since for most crops the growth stage most sensitive to salts is during the early seedling stages. Winter rain provides a less saline environment at this critical stage, enabling irrigation with more saline water during the later stages of plant growth. It is this factor that minimizes yield loss in the Mediterranean basin when irrigating with moderately saline waters. Loss of this winter rain would adversely affect crop production. Regions lacking winter rain may not be as successful when using saline waters for irrigation.

Most regions that are critically short of water are already starting to utilize waste waters for irrigation out of necessity. In many instances, these waters are not properly treated, and health risks due to food contamination with pathogens are of concern. Additional problems with reuse of all waste waters, even those that are tertiary treated, are associated with the elevated salinity SAR, pH and often boron present at concentrations adverse to plant growth (species dependent). Municipal and industrial users of water discharge added salts in their wastewater. Current waste water treatment processes utilize chlorine products to reduce or eliminate harmful microorganisms; this process inevitably results in additional increase in salinity of the treated water. Municipal treated wastewaters are always more saline than the water delivered to the municipal users. Perhaps more important than elevated salinity levels of treated wastewater is the increased SAR and pH levels relative to fresh water.

Sustainable use of treated waste water requires that we consider the impact of these waters on soil properties. The detrimental effects of elevated SAR and pH are cumulative and may take years to become evident. Use of amendments such as gypsum may be required for sustainable use of these waters, depending on site-specific conditions such as water composition, soil properties, and the extent and timing of rain events. In the absence of proper management, use of these waters may aversely affect crop production and future soil productivity. This threat is greatest in less developed nations where agricultural extension services are minimal and where the farmers are least able to afford the needed amendments to maintain productivity. This is a concern because municipal wastewater supplies are increasing with increasing municipal water demands, and the utilization of the wastewater is increasing even more rapidly. The one positive factor is that wastewater is a more reliable irrigation water supply than many current surface or groundwater sources.

Saline waters are generally abundant in arid regions. Unfortunately, most currently utilized crops of high value are salt sensitive, and most salt tolerant crops are of lower economic value. Plants also often adapt to elevated salinity by reduced transpiration and reduced growth. Current recommendations[13] are to select increasingly salt tolerant crops with increasing irrigation water salinity, thereby avoiding yield loss. These recommendations need to be reformulated in terms of absolute production (not relative) and economic return. Salt-tolerant forages such as wheat grass are available; however, optimal biomass production is lower than with some salt-sensitive forages. Therefore, total biomass production of wheatgrass under moderate salinity with no yield loss may still result in lower biomass production than would alfalfa, with its less-than-optimal yield under this salinity level.[14]

Waters currently deemed too saline for irrigation, may nonetheless be utilized in less developed nations in arid regions. Reduced yields due to salinity, while not economic in developed nations in humid regions may still be economically acceptable in more arid regions if there are no alternative water supplies. Use of saline waters will require changes in irrigation systems, crops, and management practices. For example, sprinkler systems are not recommended for application of saline waters as foliar salt damage occurs. Saline waters might be best utilized in a cyclic cropping pattern, applying saline water for more salt-tolerant species and less saline water for more salt sensitive species. Thus use of saline waters for irrigation may require significant changes in management systems and extensive farmer education to implement them.

Reuse of irrigation drainage water is another component of improved water utilization. In this instance, there is collection of the drainage water and irrigation with a more salt-tolerant crop. This can be repeated with several cycles of reuse, ending in an evaporation pond for collection of the remaining salts. A major benefit of this system is that it can avoid degradation of the existing fresh water. Such a system would enable full utilization of a water source. The feasibility of this has been demonstrated in various field studies,[15] but it is currently not widely adopted and will require infrastructure development. By implementing these reuse practices on a large scale and by keeping the drainage water separate from other water supplies, may be the only ways to avoid degradation of large supplies of moderately saline water underlying irrigated lands. These marginal waters are critical, as they will need to be utilized to sustain agriculture in arid regions.

The potential to develop salt-tolerant varieties of major food crops has not yet been realized, but increased understanding of the genetic traits of salt-tolerant plants holds the promise for breeding new suitable varieties, either via genetic engineering or by conventional breeding methods.

Conclusions

Current agricultural production in arid regions is dependent on irrigation. These arid regions are generally characterized by small irrigated parcels, which are critical to providing food to the farming family. Extraction of water in excess of what is replenished will result in reductions in available fresh water in arid regions. This reduction, along with continuing salinization of water and soils, threatens the ability of these regions to even maintain their current levels of food production and make it unlikely that they can grow sufficient food to feed their populations without technological advancements, infrastructure investment and an extensive extension system to transfer existing technology to the farmers. In the short and intermediate time frame, brackish and moderately saline ground waters are relatively abundant and can be potentially utilized to grow many, but not all crops. These practices can extend current high utilization of irrigation for decades in many countries, but will require improved and often costly management practices. The major hazard to using these waters is their elevated SAR and potential for loss of soil productivity, especially if there is significant rain. Improvements in irrigation practices, investment in new technologies, and development of salt-tolerant plant varieties may enable these regions to utilize more abundant saline waters for irrigation and slow the rate of degradation of fresh water supplies and thus extend their critical use for drinking supplies.

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