SALINATION, DESERTIFICATION, AND SOIL EROSION

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Land degradation is a collective term that describes the loss of productivity which results from soil erosion, increases in soil salinity, loss of soil structure, and so on. Various formal definitions have been offered but most include the notion of loss of productive potential, loss of biodiversity, and a move toward unsustainability and instability.

This article concentrates on the arid, semiarid and dry, subhumid regions of the world of which almost 20% of the total land area is recorded as experiencing soil degradation. The ability of soils in dry areas to recover from negative changes in the soil/land surface is lower than in humid areas. In other words, dryland soils, which cover 43% of the earth's land surface, have a low resilience.

Susceptibility to degradation by specific processes varies spatially and is affected by a range of environmental characteristics. Susceptibility to wind erosion, once a protective vegetation cover has been disturbed, is affected by particle size of distribution of the soil. Topography affects susceptibility to water erosion. Water erosion is rarely spatially continuous and usually manifests itself in scattered patches through rilling and gullying. Other characteristics such as salinization occur locally where water is available, either from groundwater sources or from perennial rivers with headwaters in more humid areas. Therefore, overall susceptibility to degradation is by no means even throughout the drylands, reflecting a range of natural antecedent conditions.

Some 1035 million hectares (Mha) of the world's susceptible drylands are affected by land degradation, of which about 90 percent are in the light to moderate categories (as defined by the UN). At the world scale, dryland degradation is dominated by water erosion (48%) and wind erosion (39%). Chemical deterioration accounts for just 4%. The situation varies according to bioclimatic zone. Wind erosion is a major cause (60%) in the arid regions while it accounts for only 21% in the dry humid regions.

There has been a rapid increase in the reports of land degradation. In much of the developing world, there has been unprecedented population increase exacerbated by the problem of using farming technologies that have shown little change and agricultural policies that are encouraging farmers to grow higher priced nonfood cash crops. This has led to excessive pressure on arable lands, rangelands, forestlands, and other land-based resources and has led to accelerated land degradation. The challenge in the twenty-first century will be to assess how land degradation can be halted and the productivity of the land lost in the past restored. This article explores the nature of land degradation, the processes involved, and looks at some measures, including remediation, to mitigate the affects of past damage.

1. Introduction

Land degradation is a collective term that describes the loss of productivity which results from soil erosion, increases in soil salinity, loss of soil structure, and so on. Various formal definitions have been offered but most include the notion of loss of productive potential, loss of biodiversity, and a move toward unsustainability and instability.

Many commentators believe that land degradation is the most important environmental threat facing humankind. This is because the resource base, on which we all depend, is either nonrenewable or only sparingly renewable. Soil formation is so slow that soil must be regarded as a nonrenewable resource. The timeframe for reclamation, and the cost, make this a less desirable option. As populations rise and demand for food and other land-based resources increase, there will be even greater pressure on the land and more incentive to overexploit it for short-term gains.

Three major types of land degradation will be dealt with here: salinity, desertification, and soil erosion.

1.1 Global Extent of Salt-affected Soils

Salinity and waterlogging, two manifestations of the salt-affected soils, are a serious threat to food fuel and fiber production in the world. On a global basis, about one-third of all agricultural lands are becoming saline. The problem, which extends to more than 100 countries, is encountered in all types of climate and is a consequence of both natural processes and human interference.
Accurate statistics on the extent of salt-affected soils are not available despite the importance of the problem, but some estimates of the extent of damage have been made. The broad distribution of saline and sodic soils around the world, both natural and human-induced, is fairly well known, as is the distribution of human-induced or secondary saline soils as identified in the UN Environment Program's survey published in the early 1990s. Salt-affected soils often have a patchy distribution, with salt problems affecting from 10% to 50% or more of the soils in a region. Table 1 indicates the best current estimates of all saline and sodic land areas, while Table 2 shows data on human-induced salt-affected soils.

There are four main points about the global salt problem:

- salt-affected soils cover a very large area of land
- the dryland regions are disproportionately affected
- saline and sodic soils are approximately equal problems
- human-induced salinity problems occur throughout many countries, in both irrigated and dryland farming districts.

Continent	Saline (Mha)	Sodic (Mha)	Total (Mha)
Africa	122.9	86.7	209.6
South Asia	82.2	1.8	84.0
North & Central Asia	91.4	120.1	211.4
Southeast Asia	20.0	-	20.0
South America	69.4	59.8	129.2
North America	6.2	9.6	15.8
Mexico/Central America	2.0	-	2.0
Australasia	17.6	340.0	357.6
Global total	411.7	617.9	1029.5

Table 1. World distribution of salt-affected areas

Continent	Light	Moderate	Strong	Extreme	Total
Africa	3.3	1.9	0.6	--	5.8
Asia	10.7	8.1	16.2	0.4	35.4
South America	0.9	0.1	--	--	1.0
North America	0.3	1.2	0.3	--	1.8
Europe	0.8	1.7	0.5	--	3.0
Australasia	--	0.5	--	0.4	0.9
Global total	16.0	13.5	17.6	0.8	47.9

Table 2. Global extent of human-induced salinization in the susceptible drylands (Mha) (source, GLASOD)

Altogether about 1 billion hectares of land have saline or sodic soils (Table 1). Human-induced salinization affects a much smaller area than natural salinity but still affects approximately 77 Mha. Salt problems affect rich and poor countries alike, but Africa and Asia are disproportionately affected.

There are two main types of salt-affected soils. The first are saline soils, which contain sufficiently high levels of sodium chloride (NaCl), sodium sulfate ($NaSO_4$), or, more rarely, other neutral salts, to inhibit the growth of crop plants. The second type of salt-affected soils are sodic, or alkaline, clay soils. They generally have low levels of total salts but contain enough of the alkali salt sodium carbonate to damage heavy soils. Sodium carbonate (Na_2CO_3) causes the clay particles in soil to disperse, or deflocculate, by ion exchange processes, resulting in a deterioration of soil structure. A sodic soil has a low permeability to water and air and a pH above 8.2. Plant growth is inhibited by negative effects of sodium on the soil and by the high pH, which reduces nutrient availability to the plant. Soils can become saline or sodic through natural processes or human-induced processes.

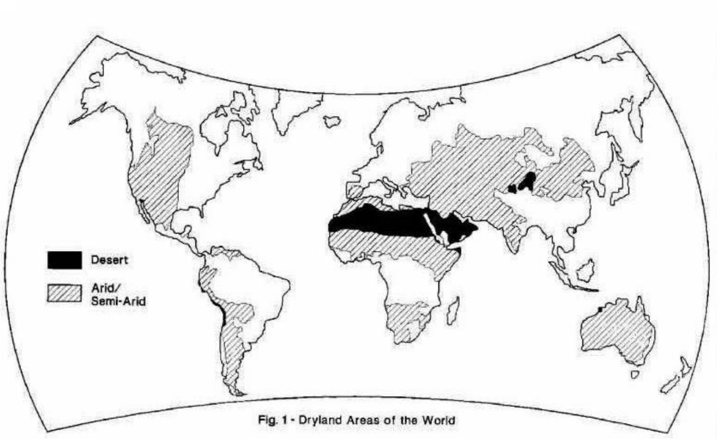

Figure 1. Map showing distribution of drylands (hyperarid, arid, semiarid and subhumid lands as defined by the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65

Natural, or *primary*, salt-affected soils are widespread especially in drylands (Figure 1) the world over because the potential evaporation rate of water from the soil exceeds the amount of water arriving as rainfall, allowing salts to accumulate near the surface as the soil dries. Vast tracts of saline soils limit the amount and quality of pasturage available. *Secondary*, or human-induced, salt-affected soils cover a smaller area than primary salt-affected soils, but secondary salinization represents a more serious problem because they mainly affect cropland.

Arable land is a scarce and valuable resource yet it is frequently abandoned when it becomes salinized, due to the high cost of repair. The problem is aggravated by the low salt tolerance of the major agricultural crops compared to wild salt-tolerant plants (halophytes) which are adapted to saline soils. Salt buildup is perhaps the biggest enemy of irrigated agriculture. Progress has been made in understanding and avoiding the practices that lead to soil salinization, and in developing new crops and agronomic techniques for salt-affected soils so they can remain in production without requiring complete restoration. Even seawater has been used to produce halophyte crops on an experimental basis, and commercial-scale plantings of oil seed crops such as *Salicornia bigelovii* have been made in Saudi Arabia .

1.2 Salt and Water Movement is the Key to Understanding Salination of Soils

The main processes of water and salt movement are:

- infiltration
- redistribution
- percolation to the water table
- drainage
- capillary rise
- soil moisture extraction by roots
- evaporation
- vertical leakage between aquifers at different depths
- groundwater flow

These processes are usually affected by changes in the hydrological cycle made by human action e.g., removal of trees, irrigation of drylands, and establishment of water distribution systems.

Salts in the landscape may originate from precipitation, weathering of deposited materials, transportation by river systems, or by ground-water flow. Quantification of these sources is necessary for a sound understanding of salt dynamics in the landscape as a whole. Land use change has had the biggest impact.

2. Land Use Practices that Lead to the Salinization of Croplands

The major factors responsible for the development of human-induced saline and sodic soils can be put down to mismanagement. Four main forms of poor management can be recognized:

1. *Use of saline groundwater for irrigation*. Groundwater is frequently saline, and prolonged buildup irrigation with such water leads to the buildup of salts in the root zone which can eventually render the land too saline for crop growth. If the groundwater is high in Na_2CO_3 rather than NaCl and the soil has a high clay content, sodic rather than saline soil conditions result. In dryland regions aquifers are rarely recharged as fast as they are pumped, hence the water table tends to be lowered and becomes more saline over time, because water is evaporated during crop production but the salts in the water are returned to the soil and aquifer. This is a common problem in inland irrigation districts throughout the drylands of the world

2. *Ingress of seawater*. Coastal arid zones often have sandy soils overlying shallow, freshwater aquifers that have accumulated over geological timespans. When these aquifers are pumped for irrigation or other uses, the water table can be quickly lowered to below sea level, allowing seawater to seep into the aquifer through the sand. Coastal irrigation districts often develop unusably high salt levels in their well fields within 10 years to 20 years of installation. On the Batina coast of Oman, hand-dug wells which sustained date gardens for centuries became salinized within a few years after the introduction of motorized pumps which extracted water from deeper levels, thereby lowering the water table below sea level and permitting seawater to enter the wells.

3. *Saline seeps in nonirrigated dryland farming regions*. When native shrubs, trees, and grasses are replaced by annual grain crops, the evapotranspiration rate of the landscape is lowered. Rainfall that would have been used up by the native vegetation instead percolates through saline subsurface sediments to impermeable horizontal layers and is conducted laterally to low spots in the landscape, producing extensive areas of salty, waterlogged soil (Figure 2). Large areas of dryland wheat farms in Australia, the US, and Canada have been salinized by this process of saline seepage (see *Quality and Quantity of Water for Agriculture*).

4. *Perched, saline water tables under irrigated fields*. The most intractable salinity problems occur in the large river basins that support vast dryland irrigation districts around the world. In its natural state a river basin has a balance between rainfall, stream flow, groundwater level, and loss of water to evaporation and transpiration When large quantities of extra water are distributed throughout the basin for irrigation, the natural balance is disrupted. Excess water seeps into soil from unlined canals, drainage ditches, and from overirrigation of the farm fields themselves. The excess water creates a high water table throughout the basin, which rises into the root zone of the crops, waterlogging the soil and inhibiting plant growth. Salts build up in the root zone over time because there is no drainage to carry them away. Glistening white salt patches in irrigated fields are, unfortunately, a common sight in many irrigation districts (Figure 3). This problem affects irrigation districts all over the world, from the lower Colorado River of the US to the Nile and Indus Valleys.

Figure 2. Total area of irrigated land - Dryland salinity is a creeping menace. As the water table rises trees die and salt begins to accumulate on the soil surface.

Figure 3. Salt-affected land showing large white accumulations of salt.

2.2. Salinity in Irrigated Lands

Irrigated agriculture has become more and more important in feeding the world's growing population. The amount of irrigated land in the world doubled every 15 years to 20 years from 1800 to 1980 and two-thirds of the world's irrigated area has been developed since 1950. By 1990, one third of the global food harvest came from irrigated fields, which represented only 17% of total cropland. Many of the new irrigation districts have been developed in dryland countries through the damming of rivers to provide irrigation water and electricity.

Since 1980, however, the trend toward irrigated agriculture has been slowing. Per capita irrigated area actually peaked in 1978 at 53 hectares per 1000 people and has decreased since then; projections were for 43 hectares by 2000. Lending by major international donors for new irrigation projects has fallen sharply.

There are several explanations for this trend. First, the best sites for irrigation have already been developed. Second, the costs of adding irrigation capacity have risen. Third, irrigated drylands have been found to be extremely vulnerable to degradation from waterlogging and salt buildup. Further expansion of irrigation into new dryland districts is seen as a risky investment. The amount of salinized land in the irrigation districts can only be estimated because exact statistics are not kept for all countries. By one estimate, 38 million hectares or 24% of the irrigated land of the top five irrigating countries has already been damaged by salt, and extrapolating to the world at large, 60 Mha are thought to have been damaged (Table 3). Another estimate puts the amount at 45.4 Mha, representing 20% of the total irrigated area. Other countries with large amounts of salt-damaged land in irrigation districts, not shown in Table 3, include Afghanistan, Egypt, Iraq, Mexico, Syria, and Turkey.

Country	Area Damaged (Mha)	Share of Irrigated Land Damaged (Per cent)
Pakistan	3.2	20
India	20.0	36
China	7.0	15
US	5.2	27
Soviet Union	2.5	12
Total	37.9	24
World	60.2	24

Table 3. Irrigated land damaged by salinization; top five irrigators and world estimate, mid-1980s

Salt damage is progressive, with more land lost to production each year in most irrigation districts. One estimate of the amount of new land that becomes salinized each year is 1 Mha to 1.5 Mha. The statistics for total irrigated acreage in Table 3 do not deduct for the amount of land lost to salt damage. Hence, a point will be reached (if it hasn't been reached already) when the total *effective* area under irrigation will actually decrease. The lost income from salinized land in the irrigated drylands is estimated in 1995 to be US$11.4 billion per year.

Estimates from different countries of losses of irrigated lands due to salinity and waterlogging vary considerably because reliable statistics are limited and definitions of degradation differ widely. Most published reports of annual global losses range from low estimates of 160 000 ha to 300 000 ha to high estimates of 1.5 Mha. In addition, estimates of areas, which are still in production but are returning lower yields because of salinity, vary between 20 Mha and 46 Mha (see also Table 3).

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Biographical Sketches

Victor R. Squires, M.A. (Hon.), Ph.D., is an Australian. He has degrees in agriculture, botany/ecology from Australian universities and did his Ph.D. at Utah State University, US. He is an Adjunct Professor at the University of Arizona, Tucson. Dr. Squires is the author or editor of several books and more than 100 papers on dryland farming, rangeland management, and the use of halophytes. He has been a consultant to UN agencies such as the FAO, UNDP. UNEP. and IFAD and has worked extensively in North Africa and East Africa, the Middle East, and China.
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