

Global Desertification Tension Zones

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ABSTRACT

Using spatial databases of global soils and climates and published information on land resource constraints, derivative maps of major land resource stresses, land quality, vulnerability to desertification, and susceptibility to wind and water erosion were developed. To evaluate the number of people affected, the map of vulnerability to desertification was superimposed on an interpolated population density map. Our analysis shows that there are about 7.1 million km² of land under low risk of human-induced desertification, 8.6 million km² at moderate risk, 15.6 million km² at high risk, and 11.9 million km² under very high risk. Each of these classes represents a desertification tension zone. The major critical tension zone that requires immediate attention is the very high-risk class. There are 11.9 million km² of land with about 1.4 billion inhabitants. Major national conflicts are related to the reduced ability of the land to support the people in agriculture-based economies. The need for mitigating technologies and aspects of policy intervention are elaborated.

INTRODUCTION

Feeding the burgeoning population while preserving or enhancing the quality of the environment is becoming a daunting task, particularly in third world countries (Eswaran et al., 1995). To ensure political stability in developing countries, decision-makers recognize food security as a primary concern -- one that overrides all others. The negative effects of desertification, the looming consequences of global climate change, declining productivity, uncontrolled urbanization, and the longer-term impacts of deforestation or resource exploitation become insignificant when compared with the immediate concerns of feeding the population (Durning, 1989). On the other hand, in developed countries, while the abilities to sustain food production and pay attention to environmental integrity are significantly better, food security is still not being addressed as a serious issue (Brown, 1993).

A first step in enhancing or even sustaining productivity is minimizing biotic and abiotic stresses and providing an optimal environment for maximizing yields. Significant advances have been made in reducing pest and disease stresses and exploiting the genetic potential of several crops. Similar progress has been made with respect to tolerance to abiotic stresses, such as resistance to moisture stress and soil acidity. This has resulted in large areas of monoclonal cultivars, which present another threat of reduced genetic diversity. An eight-to-ten fold increase in crop productivity

in the better-endowed regions of the world during the last few decades has resulted in grain surpluses. The focus on productivity and short-term returns to labor and capital of past decades has reduced land quality. In the soils of the tropics, which generally are of lower quality compared to temperate soils, damage to land quality and the environment as a whole have reached proportions never anticipated a few decades ago (Eswaran et al., 1999).

The purpose of this study is to define and locate desertification tension zones around the world where the potential decline in land quality is so severe as to trigger a whole range of negative socioeconomic conditions that could threaten political stability, sustainability, and the general quality of life. The formal definition of desertification adopted by the United Nations Convention on Desertification is, "*land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities.*" Excluded in the definition are areas which have a "hyper-arid or a humid" climate. Under low-input agricultural systems, tension zones occur in areas where the productive capacity of the land is stressed by mismanagement, generally by resource poor farmers. In high-input systems, tension zones arise due to excessive use of agri-chemicals, uncontrolled use of irrigation, and monoclonal plantations with minimal genetic diversity. In either case, probability of failure of the system is high; the difference between the two systems is the time to failure.

Common factors resulting in the development of tension zones include:

1. Excessive and continuous soil erosion resulting from over and improper use of lands, especially marginal and sloping lands;
2. Nutrient depletion and/or soil acidification due to inadequate replenishment of nutrients or soil pollution from excessive use of organic and inorganic agrochemicals;
3. Reduced water holding capacity of soils due to reduced volume of soil and reduced organic matter content, both a consequence of erosion and reduced infiltration due to crusting and compaction;
4. Salinization and water-logging from over-irrigation without adequate drainage; and
5. Unavailability of water stemming from decreased supply of aquifers and drainage bodies.

METHODOLOGY

Two databases provided the biophysical basis for our assessment of desertification tension zones: 1), the

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FAO/UNESCO Soil Map of the World at a scale of 1:5,000,000, which is now digitally available (FAO, 1991) and whose units were converted to taxa of Soil Taxonomy. 2), a climate database of the authors with records for about 25,000 stations globally, which was used in computing the soil moisture and temperature regimes. The resulting pedoclimate map was then superimposed on the soil map using a Geographic Information System (GIS). The soil and pedoclimate information was used to place each map unit into one of nine land quality classes with class I having the most favorable and class IX the least desirable attributes for grain production (Eswaran et al., 1999). To facilitate placement into these classes, a list of 24 land stresses that constrain grain production was developed. An assessment of vulnerability to desertification was then made using the procedure of Eswaran and Reich (1998).

To evaluate the number of people affected, the map of vulnerability to desertification was superimposed on an interpolated population density map developed by Tobler et al. (1995). In a second analysis, classes of population density were superimposed on the desertification map. Table 1 shows a matrix developed for this analyses. Accelerated desertification takes place with increasing population density and particularly under low-input systems. In some situations, this generalization may not be true, but this assumption was made to evaluate risk of human-induced desertification. Three classes of population density -- <10, 11-40, and >41 persons/km² -- were used and a map of these three classes was superimposed on the vulnerability to desertification map. The matrix (Table 1) was developed to relate vulnerability and population density to risk of human-induced desertification.

Table 1. Matrix for assessment of risk of human-induced desertification. The tension zones are: 1=Low risk; 2,3=Moderate risk; 4,5,6=High risk; 7,8,9=Very high risk.

VULNERABILITY CLASS	Population Density (Persons/km ²)		
	< 10	11-40	>41
Low	1	3	6
Moderate	2	5	8
High/Very High	4	7	9

By this approach, the tension zones are defined as in Table 1 and any land area represented by cells 7, 8, or 9, is considered as a critical (or at very high risk) desertification tension zone. Land belonging to the critical zone is moderate to highly vulnerable to desertification and in addition has a high to very high population density.

In a third step of the analysis we looked at the relation of serious conflicts in countries to risk of desertification. A conflict as defined by the International Peace Research Institute (IPRI) is one where at least 1,000 deaths resulted from a war. IPRI (1999) has documented countries with conflicts from 1989 to 1998.

Desertification

Desertification results from mismanagement of land and thus deals with interaction between two interlocking, complex systems: the natural ecosystem and the human social system. These interactions determine the success or failure of resource management programs. With the declaration of the Convention to Combat Desertification (CCD), culminating from decisions of the United Nations Conference on Environment and Development (UNCED, 1993) there is now an international body to address the issues of desertification. The CCD is in the process of developing an agenda and action plan for this purpose. From the land resource point of view, the thrust of a new agenda for resource assessment, monitoring, and managing the land must have at least four components, which are elaborated below:

The usefulness of soil resource information is rarely questioned. It has been the basis for many advances in agriculture. The surpluses of agricultural products in many of the western and some of the developing countries are the result of judicious use of the soil resource base. Today, the need to preserve fragile lands and enhance or maintain production on the better-endowed soils is forcing judgments on soil quality. The role of soils as a filter of chemicals and their niche in the ecosystem also require scientists to make assessments of ecosystem health. Mitigation technology for containing greenhouse gases requires scientists to evaluate soils from another perspective. All of these rely on detailed or farm-level soil information and more precise and geo-referenced information. Environmental accounting, at the other extreme, now considers soil as a capital investment and is forcing land users to include environmental costs in their production assessment.

The increasing demand for real-time information will require resource assessment to adapt. Monitoring of the quality of land resources will also be subject to the same demands. With a few exceptions, monitoring of soil properties and processes is not yet a science. It is envisaged that the future will require greater attention to changes of soil properties in addition to kinds of soils. Bouma and van Lanen (1987) have used pedo-transfer functions to estimate hydrologic events over a relatively short time frame and such studies lay the basis for the challenges of the next century. A few countries have initiated national resource inventories to monitor the status of the nation's resources. Periodic (every five years or more) assessments provide the basic information for national planning, developing mitigating technologies if large-scale detrimental changes are taking place, and for developing research priorities. Suitable indicators of resource quality assist in developing cost-effective assessments; however, more studies are required to develop such indicators for soil degradation.

The FAO/UNESCO/UNEP 'Global Assessment of Soil Degradation' provides data, albeit subjective, to evaluate the current magnitude of the soil degradation problem (Oldeman et al., 1992). The United Nations Environment Program (UNEP) and the World Resources Institute (WRI) provide other analyses on these and other aspects of environmental degradation. Although the underlying causes of land/water degradation are socioeconomic, adjustments of these factors

will not automatically restore productivity of the biophysical resource base. Thus soil and water technologies are of critical importance to ensure that production of food, fuel, and fiber can be sustained and the environment protected. Efforts to restore productivity to degraded lands should be coupled with techniques to recognize productive capacity of all soil resources. The ability to flag all stresses before productivity is significantly impaired (Brinkman, 1990) is an immediate challenge. The causes of stressed systems (Virmani et al., 1994) are numerous and include removal of nutrients, development of acidity, salinization, alkalization, destruction of soil structure, accelerated wind and water erosion and loss of organic matter. In some regions of the world, the combination of some or all of these factors results in such degradation that the term desertification is popularly used to describe these regions (UNEP, 1992). Finally, it must be appreciated that there are important interactions among the causes of degradation. Erosion, for example, may be flagged as the major problem where chemical degradation of the soil prevents establishment of vegetation and thus leads to an inability of the soil to stabilize against erosion. In this example, lack of appropriate vegetation becomes an early warning indicator. Very few studies have been conducted on this linkage between factors and there is an urgent need to re-evaluate this (Lal, 1994).

Land quality is directly linked to quality of life; specifically, social and economic equity, and thus should be addressed in the socioeconomic context for sustainability. In the past, the focus of attention was on rehabilitation of degraded lands. Thrusts in the new Agenda are to evaluate the potential for land resource degradation, manage the resilience characteristics of the systems, and select technological options in the framework of the resilience properties (Eswaran, 1993). Consequently, the concepts of 'early warning indicators' and 'land resilience' are relevant (Greenland and Szabolcs, 1994). There are few methods to predict the onset of land resource degradation, which is crucial to managing systems being stressed. The resilience capacity of systems is also less well established and this should be studied to implement remedial measures to rehabilitate degraded lands. Although soil resource information has been utilized for such purposes in developing countries, either the poor quality of information or its absence has prevented a more effective use for such purposes (Eswaran, 1992).

RESULTS AND DISCUSSION

Land quality classes (LQC) VII, VIII, and IX (Table 2) occur in the fragile ecosystems and are excluded in the following discussions due to inherent difficulties of implementing sustainable agriculture programs and also because they are excluded by the narrow definition of 'desertification'. Figure 1 shows the global distribution of the LQCs. LQCs I, II, III, have the highest potentials and least constraints for sustainable agriculture. They occupy 13.3% of the ice-free land surface and about 1.4 billion people (24.2%) live on these lands. Class IV, V, and VI lands occupy 33.4% of the land surface and as shown in Figure 1, are present mostly in the inter-tropical areas. Most of the developing countries have large areas of such lands.

About 3 billion people (52% of global population) live on these lands. They are mostly poor and practice low-input/low-output agriculture. Large areas of these lands have long periods of soil moisture stress, which is the main cause of reduced soil quality. In the areas with a humid climate, plantation agriculture provides the wealth of the country.

The implication of this analysis is that more than 75% of the world's populations live in regions that do not have a high capacity for grain and feed production. When population densities were low, the land supported the people. However, with increasing population not only does the ability of the land to support the population become threatened but the negative consequences of low-input systems also systematically reduces this ability.

Table 2. Estimate of population in designated land quality classes. Note: The global population density map is limited to latitudes 72°N to 57°S.

Land Quality Class (LQC)	Land area		Population	
	Million km ²	Percent	Millions	Percent
I	4.09	3.2	337	5.9
II	6.53	5.0	789	13.7
III	5.89	4.5	266	4.6
IV	5.11	3.9	654	11.4
V	21.35	16.3	1,651	28.8
VI	17.22	13.2	675	11.8
VII	11.65	8.9	639	11.1
VIII	36.96	28.3	103	1.8
IX	21.78	16.7	625	10.9
Global	130.6	100.0	5,759	100.0

The land qualities and climatic properties without considering availability of irrigation were employed to make the assessment of vulnerability to desertification. Figure 2 and Table 3 show the results of this analysis. Comparing Figures 1 and 2, it is clear that many of the lands that are vulnerable belong to LQC IV, V, and VI. The high to very high desertification vulnerability classes occupy about 11.6% of the global land surface.

Table 3. Estimates of land area belonging to vulnerability classes and corresponding number of impacted population. Note: The global population density map is limited to latitudes 72°N to 57°S.

VULNERABILITY CLASS	AREA SUBJECT TO DESERTIFICATION		POPULATION AFFECTED	
	Area (million km ²)	Percent (Global land area)	Number (Millions)	Percent (Global Pop.)
Low	14.60	11.2	1,085	18.9
Moderate	13.61	10.5	915	15.9
High	7.12	5.5	393	6.8
Very High	7.91	6.1	255	4.4
TOTAL	43.24	33.3	2,648	46.0

Desertification processes impact about 2.6 billion people or 44% of the world's population (Table 3). Many of them are probably contributing to the process as they live in the developing countries of the world where good land management is not the rule. There are, of course, considerable differences between countries with respect to high population impacts on land degradation. Cleaver and Schreiber (1994) estimate that about 50% of Sub-Saharan agricultural land has lost its productivity due to degradation and about 80% of rangeland show signs of degradation. Shifting cultivation with long fallow periods and transhumance pastorals was appropriate in the past when populations were low. However, in many countries this steady state is being tilted towards exploitation of the resource base. The slow evolution to more intensive and permanent systems without appropriate inputs is contributing to the decline of land quality. A similar process is also operating in many countries of Asia.

As shown in Table 1, a high population density in an area that is highly vulnerable to desertification poses a very high risk for further land degradation. Conversely, a low population density in an area where the vulnerability is also low poses in principle a low risk. Figure 3 shows the distribution of the risk of human-induced desertification and Table 4 gives the areas of the classes. The Mediterranean countries of North Africa are very highly prone to desertification. In Morocco, for example, erosion is so extensive that the petrocalcic horizon of some Palexeralfs is exposed at the surface. In the Sahel, there are pockets of very high-risk areas. The West African countries, with their dense populations, have major problems containing the processes of desertification. There are large areas of Central and Southern Asia, which are highly vulnerable. In South America, the northeast corner of Brazil (the province of Pernambuco) is highly vulnerable.

Table 4. Land area (1,000 km²) in human-induced desertification risk classes. (See Table 1 for computation).

Vulnerability Class	Population Density (Persons/km²)		
	<10	11-40	>41
Low	7,111	3,202	4,285
Moderate	5,432	3,950	4,222
High/Very High	7,366	4,446	3,213

There are about 7.1 million km² of land at low risk of human-induced desertification, 8.6 million km² at moderate risk, 15.6 million km² at high risk, and 11.9 million km² at very high risk. Each of these classes represents a tension zone. However, the critical tension zone, which requires immediate attention belongs to the very high-risk class. There are 11.9 million km² of such lands (Figure 3, Table 4) and about 1.413 billion people are involved. The concept of desertification suggests some or all of the following negative effects and the probabilities of their occurrence are highest in the tension zones:

- Systematic reduction in crop performance even

leading to failure in rainfed and irrigated systems;

- Reduction in land cover and biomass production in rangeland with an accompanying reduction in quality of feed for livestock;
- Reduction of available woody plants for fuel and increased distances to harvest them;
- Significant reduction in water from overland flows or aquifers and a concomitant reduction in water quality;
- Encroachment of sand and crop damage by sand-blasting and wind erosion;
- Increased gully and sheet erosion by torrential rain;

As a consequence of some or all of these processes, there commonly occurs societal disruption due to reduction in life-support systems. It is difficult to establish cause and effect relationships between conflicts and ability of land to feed and clothe the people. In Figure 4, the location of major conflicts during the period 1988 to 1998 is indicated on the map of tension zones. The coincidence may be accidental but it does provide a reason for concern. Some high-risk countries such as Nigeria and India have not had major conflicts due to counteracting policies. However, the potential of conflict is high and continuous vigilance is necessary. The countries ravaged by civil war such as, Rwanda, Burundi, Ethiopia, Somalia, Kampuchea, and in parts of countries such as in Sri Lanka, Angola, Mexico, and former Yugoslavia may have different reasons for the conflicts. Invariably communities threatened by land shortages generally trigger it. Race, religion, origin of population and even caste may be used as reasons for the conflict but an underlying reason is generally land and its quality.

CONCLUSION

Designation of tension zones is an important prerequisite for formulating national policies that address land degradation and desertification. In the present global assessment, only the quality of the land and the population density are used to identify and delineate the tension zones. Knowledge of other factors, specifically socioeconomics and more detailed resource characteristics including quality and quantity of water, is necessary for national appraisal. A comprehensive analysis should consider the nexus of high population densities, quality and quantity of the resource base, agricultural production systems, and environmental factors. The next step should be to develop a framework for desertification tension zone assessment and monitoring with suitable indicators. Such an analysis would provide a basis for appropriate policies and mitigation technologies.

Identification and location of desertification tension zones in countries, if followed-up with appropriate policy decisions and action plans, will help to:

- Enable the judicious use of land resources through protection and preservation of fragile systems and sustainable production on the better endowed areas, and targeting of research and development; ensure a balanced land use through appropriate land allocation for forestry, wild-life, agriculture, and urban use; and promote a more rational use of the scarce water resources;

- Buffer the socioeconomic stresses and reduce economic instability and political unrest in the country as a whole; reduce pressures on affected areas and promote sustainable development outside the affected areas;
- Alleviate pressures on biodiversity and promote environmental integrity;
- Help reduce the iterative processes leading to global climate change through increased land cover and as a result, enhance carbon sequestration; and
- Assure food security and a better quality of life for most of the people.

A *sine qua non* to help address global land resource constraints to sustainable agriculture is the identification and quantification of land resource stresses. This would assist in prioritizing the allocation of funds to alleviate constraints of poorer countries and set them on the path to sustainability. With the current knowledge of soil resources and climatic endowments of countries, it is possible to identify the tension zones and develop a basis for future quantitative assessments of land degradation and even desertification.

REFERENCES

- Brinkman, R. 1990. Resilience against climate change. In: (Eds. Scharpenseel, H.W., M. Shoemaker, and A. Ayoub). "Soils on a Warmer Earth". Elsevier, Amsterdam. 51-60.
- Brown, L.R. 1993. A new era unfolds, 3-21. In: L. Starke (ed.) State of the World, 1993. Worldwatch Institute and Norton Publ. Co. New York.
- Cleaver, K.M. and G.A. Schreiber. 1994. Reversing the Spiral: The population, agriculture, and environment Nexus in Sub-Saharan Africa. The World Bank, Washington D.C. 293 pp.
- Durning, A.B. 1989. Actions at the grassroots: Fighting poverty and environmental decline. Worldwatch Paper 88. Worldwatch Institute, Washington D.C.
- Eswaran, H. and P. Reich. 1998. Desertification: A global assessment and risks to sustainability. In: Proc. Of 16th Intl. Congr. Soil Science, Montpellier, France. CD ROM.
- Eswaran, H., F. Beinroth, and P. Reich. 1999. Global land resources and population supporting capacity. Am. J. Virmani, S.M., J.C. Katyal, H. Eswaran, and I.P. Abrol. 1994. (ed.), Stressed Ecosystems and Sustainable Agriculture. Oxford and IBH Publ. Co. Ltd., New Delhi.
- Alternative Agric. 14:129–136.
- Eswaran, H. 1992. Role of soil information in meeting the challenges of sustainable land management (18th Dr.R.V. Tamhane memorial lecture). J. Indian Soc. Soil Sci. 40:6-24.
- Eswaran, H. 1993. Soil resilience and sustainable land management in the context of Agenda 21. In: Greenland, D.J. and I. Szabolcs (Eds.) Soil Resilience and Sustainable Land Use. CAB International. Wallingford, England. 21-32.
- Eswaran, H., S.M. Virmani, and I.P. Abrol. 1995. Issues and challenges of dryland agriculture in Southern Asia. In: A.S.R. Juo and R.D. Freed (ed.) Agriculture and the Environment: Bridging Food Production and Environmental Protection in Developing Countries. ASA Spec. Pub. 60:161-180. Madison WI.
- FAO. 1991. The digitized Soil Map of the World. World Soil Resources Report 67/1 (Release 1.0), Food and Agricultural Organization, Rome.
- Greenland, D.J. and I. Szabolcs (eds). 1994. Soil Resilience and Sustainable Land Use. CAB International, Wallingford, U.K.
- IPRI, 1999. To cultivate peace: Agriculture in a world of conflict. Unpublished internal report. International Peace Research Institute, Oslo, Norway.
- Lal, R. 1994. Methods and Guidelines for Assessing Sustainable Use of Soil and Water Resources in the Tropics. SMSS Technical Monograph No. 21. Washington, D.C., 78 pp.
- Oldeman, L.R., R.T.A. Hakkeling, and W.G. Sombroek. 1992. World map of the status of human-induced soil degradation: an explanatory note. Wageningen, Netherlands: International Soil Reference Center. 34 pp.
- Tobler, W., V. Deichmann, J. Gottsegen, and K. Maloy. 1995. The global demography project. Technical Report TR-95-6. National Center for Geographic Information analysis. Univ. Santa Barbara, CA. 75 pp.
- UNCED, 1993. AGENDA 21: program of action for sustainable development. United Nations, New York. 294 pp.
- UNEP, 1992. World Atlas of Desertification. Publ. E. Arnold, London. 69 pp.