LAND DEGRADATION AND DESERTIFICATION: HISTORY, NATURE, CAUSES, CONSEQUENCES, AND SOLUTIONS

Conacher, Arthur
School of Earth and Geographical Sciences, University of Western Australia, Australia

Keywords: Salinization, waterlogging, irrigation, population growth, urbanization, environmental quality indicators, measurement, complexity, socio-economic consequences, research, human actions, climate change, integrated solutions, planning, regions.

Contents

Summary

Desertification can be considered to be a subset of land degradation, occurring in more arid areas; though land degradation is usually defined as being caused by human actions. The main direct actions are over-clearing, over-grazing and over-cultivation. There is a host of more complex direct and underlying causes including the introduction and spread of exotic plants, animals, pests and diseases, fire, economic pressures,

people's attitudes, perceptions and knowledge, actions or inactions by government agencies, and inappropriate government policies. The result is the deterioration of vegetation, soil and water resulting in the decreased health of ecosystems and the capacity of the biophysical environment to support human populations. The problems are not new, but they have been exacerbated over the last century by rapid population growth, increased areas subject to irrigation and urbanization, and the demands on the biophysical environment arising from the change from essentially peasant-type societies to technologically-based economies.

Research focuses on all aspects of land degradation: the detailed biophysical processes; human actions and responses; and means of solving the problems. The latter are particularly complex as solutions need to deal with human behavior, decision- and policy-making as well as technical, social and economic aspects. Government support for regionally-based planning to devise and implement solutions is essential. However, most research in the past has been directed towards the physical processes of land degradation, often with a geomorphic emphasis. Only recently have some international research groups such as the International Geographical Union's Commission on Land Degradation and Desertification sought to explicitly incorporate social science methods in researching the human aspects of this major global problem. In combination with programs such as the land-use planning guidelines of the United Nations' Food and Agriculture Organization, the biophysically- and human-based research of the geographers has the potential to make a significant contribution to improved management practices in the regions most severely affected by land degradation.

1. Introduction

Desertification means the transformation of land into desert-like conditions. Some refer to it simply as 'land degradation in drylands', whereas the UN Convention to Combat Desertification defines it as '*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.*'
http://www.unccd.int/convention/text/convention.php

Threats to drylands come from both socio-economic and biophysical changes, with root causes as well as consequences often being poverty, insecurity and harsh climates. Wars should be added to this list. Additionally, institutional and policy factors at different spatial and temporal scales are poorly understood and data are inadequate.

Similar comments can be made about land degradation. However, land degradation occurs in all climatic environments, and the symptoms are much broader than the term 'desert-like' implies. Land can be degraded in a number of ways and is usually interpreted to include vegetation and water as well as landforms and soils. Thus land in humid temperate environments with a good vegetative cover is degraded if, for example, the soils have been contaminated by toxic chemicals or water bodies have become eutrophic. Diseased vegetation is 'degraded'. Both 'desertification' and 'degradation' imply adverse consequences for people and ecological systems. However, land degradation is usually considered to result from human actions, not natural events; and is thereby distinguished from both 'natural hazards' and desertification as defined above. Thus, Arthur and Jeanette Conacher defined land degradation as *'alterations to all aspects of the biophysical environment by human actions to the detriment of vegetation, soils, landforms, water, ecosystems and human well-being.'*

However, Monique Mainguet proposed the following definition: *Desertification, revealed by drought, is* caused *by human activities in which the carrying capacity of land is exceeded; it proceeds by exacerbated natural or man-induced* mechanisms, *and is made manifest by intricate steps of vegetation and soil deterioration which* result, *in human terms, in an irreversible decrease or destruction of the biological potential of the land and its ability to support population.*

She distinguishes between causes, mechanisms, manifestations and impact of desertification. Unlike the UN Convention to Combat Desertification (above) she considers human actions to be the cause and droughts as the 'revealer'. The interesting new element in her definition is the introduction of the term 'irreversible'. Many scientists would probably prefer this term to be removed from the definition: we do not like to admit defeat.

1.1 Structure of the Chapter

This chapter first considers briefly the history of land degradation with some comparisons between the 'old' and 'new' worlds and consideration of the data or evidence. The various forms of land degradation are discussed. Research into the nature, extent and causes of land degradation is then reviewed; it is necessary to understand the causes of the problems before attempting to provide solutions. Reference is made to the controversy over the human versus climatic causes of desertification. The (mostly human) consequences of land degradation and desertification are then outlined. The need for integrated solutions is stressed: problems must not be tackled on a one by one basis, in isolation from one another. However, this raises the questions: What are the appropriate spatial units (and scales) for implementing solutions? How can solutions be implemented (what methods can be used)? And who is or should be responsible for planning and then implementing the solutions on the ground?

2. A Brief Historical Review of Land Degradation

Since land degradation (unlike desertification) is defined as resulting from human actions, the global introduction and spread of the problem are closely related to the introduction, spread and growth of human populations and their increasing demands on the natural resource base. However, as has been said many times, numbers alone are not the sole cause: land-use practices, which in turn are influenced by technology amongst a range of other factors, are the primary underlying cause.

Although humanity is thought to have originated in Africa's rift valley region, the first reasonably well-documented instance of land degradation comes from what used to be called Mesopotamia; the irrigated lands in the Tigris and Euphrates river systems. Here, as in other irrigated drylands of North Africa and later Pakistan, California and elsewhere, the main problems were (and are) secondary salinization, related to waterlogging. Associated with this was a serious decline in soil fertility.

The early initiation and growth of urban civilizations in Mesopotamia in the later part of the 4th millennium BC was related to the development of irrigation. The main crop was wheat. Increasing salinity is reported to have caused a shift from wheat to the more salt-tolerant barley: by around 3500 BC the proportions of the two crops were roughly equal, and by 1700 BC wheat had been abandoned completely. Eventually even barley could not be grown and the populations of the kingdoms of Sumer and Akkad had to abandon the area. Historical evidence from other regions in China, the Indus River Basin, South America and Arizona indicates that similar problems permeate our history. The process forced people to shift to other locations which, in turn, also became salinized in many cases.

In the 'new world', British engineers in the later part of the 19th century constructed large-scale irrigation schemes in India and Pakistan, resulting in rising water tables and extensive salinization and soil degradation. In the 1950s, the Amu Darya and Syr Darya (rivers) in the Commonwealth of Independent States (CIS) were diverted from the Aral Sea to irrigate cotton and rice, producing some 90 per cent and 40 per cent of the former USSR's cotton and rice production respectively. This has resulted in the drastic shrinkage (by more than 40 per cent) of the Aral Sea, devastating effects on flora and fauna, degraded ecosystems, serious health hazards and climate changes in the region. The irrigated San Joaquin Valley in California is extensively salinized and poisoned by selenium, and parts are also subject to wind erosion and land subsidence — the latter ironically due to over-extraction of ground water.

Salinization and waterlogging of irrigation areas are only two closely related, and perhaps the earliest, forms of reported land degradation. Although human habitation extends back over many thousands of years, the introduction of more 'advanced' forms of agriculture in particular (including irrigation, referred to above) has been responsible for the more serious forms of land degradation. This is well encapsulated in the following quote modified from Dean Graetz and others in 1992:

For more than 40 000 years, Australia supported at least 1200 generations of humankind, providing life in that time to an estimated 360 million Australians as hunter-gatherers. Although this was not without its impact on the landscape, particularly through the Aboriginal use of fire, European agriculturalists in just five generations have altered the face of the Australian continent far more dramatically than had been done by all those who had gone before.

Nevertheless, mostly 'peasant' forms of agriculture also transformed landscapes, particularly through modifications to vegetation by shifting agriculture, the more permanent clearing of land for crops and pastures and, in many regions, the construction of terraces on steep land; especially in parts of Asia, some Mediterranean lands, and in parts of South America. Whether such transformation should be equated with 'degradation' is debatable. There is ample evidence to show that land continued to be productive for thousands of years: soils were cultivated carefully by hand and with the aid of animals; soil fertility was maintained and improved by the return of manures. Even 'slash and burn' agriculture has been shown to be less detrimental to the land than modern, mechanized forms of agriculture.

The extent to which traditional forms of agriculture — including pastoralism — degraded the land was and is to some extent influenced by the nature of the biophysical environment. Steep slopes are clearly more susceptible than gently-sloping land to accelerated erosion; low-lying flood plains and flat lands are more likely to be affected by flooding; regions affected by strongly seasonal climatic regimes are affected by both floods and droughts; areas with highly flammable vegetation are more prone to fire; drylands with sparse vegetation cover are more exposed to wind erosion, and so on. However, over many centuries, and as a matter of necessity, traditional agriculturalists learned how to live 'with' nature. It has been mainly since the 18^{th} and 19^{th} centuries that exponential rates of population increase in much of the Third World, and mechanization and the onset of chemical farming worldwide, have resulted in some very serious problems. Global warming — at least partly caused by the increasing release of 'greenhouse gases', with agriculture being a significant contributor — is already affecting plants and animals, as reported by Parmesan and Yohe in 2003.

Population growth has also given rise to the increasing phenomenon of urbanization. In many countries most people now live in cities, and rural to urban population migrations continue. Some cities have grown to sizes that would have been unimaginable only a few decades ago: 20-million-plus mega-cities are increasingly common, whilst million-plus cities barely rate a mention. The 'ecological footprint' of these mega-cities is huge. They depend on vast areas, internationally, for their food and water, energy, clothing, building materials and manufactured goods. In turn they impact on their more immediate and distant surrounds with their unwanted solid, liquid and airborne wastes and they affect both local and global climates.

Land degradation *within* cities is massive: the natural environment has been totally transformed. In most cities attempts are made to retain areas of natural vegetation, to maintain the quality of waterways, to dispose of solid waste in 'sanitary landfills', to process human wastes and to control flooding, subsidence and air pollution. But in the megacities, even in the First World, it seems that these efforts are often futile. The environmental problems of the Calcuttas, Mexico Cities, São Paulos, Cairos, Bangkoks, Chongqings and Shanghais of the world seem to be increasingly insurmountable.

In response to these problems, many of which are also related to human health as well as degraded ecosystems and loss of biodiversity, a number of global treaties and agreements have been negotiated under the auspices of the United Nations. One of the outcomes of some of these agreements has been attempts to obtain improved data on the state of the planet. Countries around the world have been encouraged to carry out and publish 'state of the environment' (SoE) reports and to adopt sustainability strategies. The purpose of SoE reporting, usually on a five-yearly basis, is to track changes and identify trends; both worsening and improving. This then provides a basis for action by the various jurisdictions. One of the requirements to enable this to be done on a reasonably objective basis is the identification of an agreed set of 'indicators' of environmental quality. The OECD (Organization for Economic Co-operation and Development) has developed one set of indicators (which include socio-economic as well as biophysical environmental attributes), as have other organizations and a number of countries. In the future there will be much improved databases on the state of the global environment and, within that broad area, the changing status of land degradation.

By way of illustration, the OECD indicators were modified in Australia and New Zealand in an ANZECC (Australia and New Zealand Environment and Conservation Council of Ministers) discussion paper in 1998. The Ministers noted that the set of core indicators can be supplemented in each jurisdiction by additional indicators to accommodate particular management, scale or environmental issues as required. Some important variables were not measured because of data limitations or scientific uncertainty regarding the accuracy of measurement techniques. They further noted that indicators need to be: scientifically credible; useful and robust in tracking trends; readily interpretable; relevant to policy/management needs, and cost effective. Seventy-two core indicators are described under six themes: the atmosphere; biodiversity; the land; inland waters; estuaries and the sea, and human settlements. A seventh theme, natural and cultural heritage, was being developed. Core, key or primary indicators are those that are considered to be the most sensitive in recording change. In general they reflect ecological processes and can be subdivided into physical, chemical and biological indicators. Secondary indicators are less sensitive and provide additional information on biophysical, social and economic inputs or outputs and may help to explain causal links between human activities and environmental impacts. Many indicators overlap amongst the themes and are often complex.

Indicators can be grouped in another way. As done for the 2001 Australian State of the Environment Report, indicators can be grouped into those measuring *pressures* on the environment, those measuring the *state* of the environment, those measuring the *responses* of a broad range of groups in society to both the pressures on and the state of the environment, and finally those that measure the *implications* of the trends in the different measures for environmental conservation.

Whilst the indicators work outlined above was directed at environmental quality monitoring, much of it is relevant to the assessment of land degradation. It is therefore appropriate to consider more closely just what should (or could) be included in that assessment.

3. The Forms of Land Degradation

As indicated in the Introduction to this chapter, land degradation has a number of aspects. They include a range of measurable properties relating to vegetation (and, sometimes, fauna), soils and water, soil erosion, droughts and floods. The idea of ecosystem viability, or health, is useful in bringing some of these aspects together rather than considering them as unrelated, isolated characteristics of the overall problem.

3.1. Flora and Fauna

Vegetation is often the first element of the biophysical environment to be degraded by human actions, or perhaps it is the most visible. It is also that element identified most readily by remote sensing, except in arid and frozen environments. Its decomposition (by chewing and fungal and bacterial processes) forms humus and releases nutrients into the soil, many of which are then cycled back into the plants. Vegetation importantly provides habitat, directly for insects and also nesting sites, shelter and food (directly and indirectly) for larger biota. Loss of native vegetation therefore directly threatens ecosystem processes and the survival of animals and birds. Vegetation degradation often leads to loss of soil fertility, accelerated erosion and reduced water quality (and changed flow regimes), thereby threatening the viability of human communities.

Measurable aspects of biota include numbers of individuals and species, incorporating species diversity and composition. With regard to degradation, the reduction of populations to the extent of placing species under threat or even resulting in extinctions is also measurable, albeit with some degree of uncertainty. This uncertainty is particularly the case for smaller biota, mainly insects. In many locations a large proportion of insect species has still to be identified, including the important litter and soil fauna. On the other side of the coin are increased numbers of individuals and species as a result of the introduction of alien species; weeds in the case of vegetation and feral animals and harmful pathogens in the case of biota. Air travel and transfers of bilge water in ships have meant the inevitable globalization of living organisms, including viruses and bacteria.

Structural aspects such as height and density at different levels, including ground cover, refer more to vegetation than to fauna. Biomass is a common measurement of ‘productivity’. Health is also important but more difficult to measure and quantify on a spatial as distinct from an individual basis. Even though the morphology and numbers of plant and animal individuals and communities may appear healthy, they may be suffering stress from insect and fungal attack, depleted or imbalanced soil nutrients, and deteriorating soil- and ground-water or air quality.

Ecological processes also need to be included, especially food chains and energy flows; but again posing difficulties for measurement. Research such as that reported by Moldan and Cerny in 1994 on the biogeochemistry of small catchments is of particular value in the context of measuring nutrient fluxes.

3.2. Soil Degradation

The United Nations Environment Programme (UNEP) has produced a map showing global soil degradation. Three classes are depicted: high to very high, low to medium and non-degraded based on the percentage of the mapping unit affected and the degree of degradation. However, the reliability of such maps is questionable. Apart from issues of data quality, which in many regions is poor to non-existent, there is the question: what is being measured?

Degradation of soil properties can be measured in three groups: biological, chemical and physical/morphological properties.

The degradation of soil biological properties usually refers to declining soil organic matter (or carbon) and reduced macro and micro soil and litter fauna. Soil organic matter, especially humus, is important for several reasons: it contributes cohesion to the soil, provides nutrients and stores water. Soil and litter fauna are crucial. Their role in bioturbation, which affects soil texture, organic matter and a range of chemical properties, thereby maintaining soil fertility, is fundamental. In 1882 Charles Darwin wrote perceptively about the role of earthworms in soil formation. More recently (in

1990), Lisa Lobry de Bruyn and Arthur Conacher reviewed the extensive literature on the pedological roles of ants and termites.

Declining soil fertility is measured by the loss of soil nutrients, usually the NPK triumvirate (nitrogen, phosphorus and potassium). But trace elements are also essential and are often excluded from standard synthetic fertilizing practices. Synthetic fertilizers also do not contribute to organic matter or to soil physical properties such as soil structure, water holding capacity and cohesion.

Elemental imbalances are an important aspect of soil chemical properties in relation to soil degradation. Some of the most important imbalances worldwide are acidification, sodification and salinization. Most soils become increasingly acid over time as bases are leached out of the system in soil-water or by plant uptake. Some fertilizing practices contribute to the problem. Lime is usually required to treat the symptoms of the problem. Sodification refers to the accumulation of excess sodium ions in the soil, and is characteristic of many soils in semi-arid environments. It is also influenced by the parent materials. The consequences are mainly a loss of soil structure, enhancing waterlogging and some erosion processes, and causing difficulties for plant root penetration and loss of oxygen in the root zone. Salinization refers to the hyper-concentration in soils (and water) of naturally occurring soluble salts, usually chlorides, sulfates and carbonates, and the accumulation of artificial nutrients associated with fertilizers and pesticides. In the former instance the causes of the salt concentrations are hydrological changes resulting from either irrigation or the replacement of natural vegetation with introduced crops and pastures (secondary, dryland salinization). Primary salinity refers to areas that were naturally saline such as saline playas in more arid areas or coastal marshes (that is, not caused by human land-use practices).

Elemental imbalances in soils also result from the addition of toxic elements and compounds. Phosphate fertilizers, for example, include traces of cadmium and uranium, amongst other impurities. In areas such as market gardens (truck farming), where there are high rates of fertilizer applications, cadmium accumulates in soils and in different parts of vegetables, with potentially adverse effects on consumers of the vegetables. Toxic elements and compounds are also added to soils by air pollution, with acid rain and airborne lead being well-known instances. The disposal of toxic wastes in landfills is another, obvious example. It seems that not until adverse health effects are reported in significant numbers of people is any effective action taken to control or redirect this disposal, whilst the construction of residential areas on and around hazardous waste dumps (unknowingly or otherwise) appears to be an increasingly frequent occurrence.

Soil physical and morphological properties reflecting degradation include loss of soil structure and compaction. Lateritization (the irreversible hardening of soils following their exposure to the atmosphere, as occurred in Brazil following the replacement of rainforests with coffee plantations) is a particular instance. Accelerated erosion by wind and water, and desertification, are other aspects of soil degradation. Data on human-induced erosion rates are not difficult to find: the question is the extent to which this has accelerated in comparison with natural (pre-human occupation), geomorphic rates. Erosion is a natural process. Even in countries where clearing of natural vegetation is relatively recent this is a difficult question to answer. The other comparison that is made from time to time, is with rates of soil formation. Ideally, erosion rates should not exceed soil formation rates. But the latter are even more difficult to measure than natural erosion rates. Which soil property is to be measured to determine its rate of formation? As has been shown by Huggett, different properties develop at different rates. Since erosion is usually expressed as volume (or mass) per unit area over time, or as the removal of a certain thickness again over time, soil formation rates should be expressed similarly for comparison. Mass or thickness of what soil properties, however? Accumulation of litter, soil organic matter, a particular range of particle sizes, or secondary clay minerals; thickness of the A horizon (how determined quantitatively); depth of 'solum' (can this be defined accurately?); total soil depth (to what — unweathered parent rock? How do we deal with deep regoliths?).

-
-
-

Bibliography

Australian State of the Environment Committee (2001). Australia State of the Environment 2001, Independent Report to the Commonwealth Minister for the Environment and Heritage, Canberra, Australia: CSIRO Publishing on behalf of the Department of Environment and Heritage. [An excellent example of a State of the Environment (SoE) report including the use of the Pressure-State-Response model and environmental indicators.]

Bradstock, R.A., Williams, J.E. and Gill, M.A. (eds) (2002). Flammable Australia: the Fire Regimes and Biodiversity of a Continent, Cambridge, UK: Cambridge University Press. [A thorough treatment of the many complexities associated with fire.]

Chappell, A. and Agnew, C.T. (2001). Geostatistical analysis and numerical simulation of West African Sahel rainfall. In Conacher, A.J. (ed.), Land Degradation, 19–35. Dordrecht: Kluwer. [Detailed assessment of the data pertaining to a major desertification controversy.]

Conacher, A.J. and Sala, M. (eds) (1998). Land Degradation in Mediterranean Environments of the World: Nature and Extent, Causes and Solutions, Chichester: Wiley. [An extensive compilation of work by contributors from the Mediterranean regions.]

FAO (1993). Guidelines for Land-Use Planning, FAO Development Series 1, Rome: Food and Agriculture Organization of the United Nations. [A planning framework based on many years experience on the ground, developed by the FAO mainly for developing countries but relevant to devising practicable plans to deal with land degradation in all environments.]

Geeson, N.A., Brandt, C.J. and Thornes, J.B. (eds), (2002). Mediterranean Desertification: a Mosaic of Processes and Responses, Chichester: Wiley. [The most recent publication of the MEDALUS program.]

Ghassemi, F., Jakeman, A.J. and Nix, H.A., 1995: Salinization of Land and Water Resources: Human Causes, Extent, Management and Case Studies, Sydney, Australia and Wallingford, UK: University of New South Wales Press, and CAB International. [A good worldwide coverage of the important problem of salinization.]

Inbar, M. (2002). A geomorphic and environmental evaluation of the Hula drainage project, Israel. Australian Geographical Studies 40, 155–166. [A specific example of the unexpected consequences that can emerge from projects designed to increase agricultural production.]

Mainguet, M. (1991). Desertification: Natural Background and Human Mismanagement, Berlin: Springer-Verlag. [A sound, well-known text bringing a broad perspective to bear on desertification.]

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 37–42. [Presents evidence that global warming has already resulted in lateral (and vertical, in mountainous terrain) displacement of plants and animals.]

Biographical Sketch

Arthur Conacher is Associate Professor of Geography in the School of Earth and Geographical Sciences at the University of Western Australia. He holds a Doctor of Science degree awarded in 1991 by the same university for his published work in environmental science. He has published over 100 refereed papers and book chapters; and is author, co-author, editor or co-editor of a number of research monographs and books. Four books on land degradation and environmental planning and management have been published (by Wiley, Oxford University Press and Kluwer) since 1995. Much of his research has been carried out in Australia; but he has also worked in most of the world's Mediterranean climate type environments, as well as lecturing in New Zealand, England and Canada. He has supervised research by 15 postgraduate and more than 50 honors students.

Initially, Dr Conacher's research was in the field of pedo-geomorphology, helping to formulate the nine unit land surface model. Interest then developed in the nature, extent and causes of secondary salinity in south western Australia, and the environmental, political and decision-making implications of clear felling of native forests for the export woodchip industry in Western Australia. These interests broadened into land degradation more generally on the one hand, and environmental planning and management on the other.

As Secretary of the International Geographical Union's Commission on Land Degradation and Desertification (COMLAND) since 1996, Dr Conacher has assisted with the organization of (and participated in) conferences and field trips in a range of countries, including South Africa, Mexico, Argentina, Japan and Iceland as well as organizing an international meeting in Perth. He is editor (physical and environmental geography) of *Australian Geographical Studies: Journal of the Institute of Australian Geographers*, and is a member of the editorial board of the *Australian Geographer*. He convenes the Environmental Sustainability study group of the Institute of Australian Geographers. As a member of the Policy and Practice Committee of the Environment Institute of Australia and New Zealand from the mid 1990s to 2003, he wrote the initial drafts of Institute policies on environmental impact assessment, public participation, and environmental education.

He has had three periods as Head of the (previous) Department of Geography and was Alternate Dean and then Dean of the (previous) Faculty of Science at the University of Western Australia for four years. Until 2004 he was Associate Dean for Environmental Science and Geography in the Faculty of Natural and Agricultural Sciences at the same University.