Advances in Water Resources 51 (2013) 326–344

Contents lists available at SciVerse ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

Global desertification: Drivers and feedbacks

Paolo D'Odorico [a,*], Abinash Bhattachan [a], Kyle F. Davis [a], Sujith Ravi [b], Christiane W. Runyan [a]

[a] Department of Environmental Sciences, University of Virginia, 291 McCormick Road, Charlottesville, VA 22904-4123, USA
[b] Biosphere 2, University of Arizona, Tucson, AZ 85721, USA

ARTICLE INFO

Article history:
Available online 13 February 2012

Keywords:
Desertification
Land degradation
Ecohydrology
Feedbacks
Overgrazing
Soil salinity

ABSTRACT

Desertification is a change in soil properties, vegetation or climate, which results in a persistent loss of ecosystem services that are fundamental to sustaining life. Desertification affects large dryland areas around the world and is a major cause of stress in human societies. Here we review recent research on the drivers, feedbacks, and impacts of desertification. A multidisciplinary approach to understanding the drivers and feedbacks of global desertification is motivated by our increasing need to improve global food production and to sustainably manage ecosystems in the context of climate change. Classic desertification theories look at this process as a transition between stable states in bistable ecosystem dynamics. Climate change (i.e., aridification) and land use dynamics are the major drivers of an ecosystem shift to a "desertified" (or "degraded") state. This shift is typically sustained by positive feedbacks, which stabilize the system in the new state. Desertification feedbacks may involve land degradation processes (e.g., nutrient loss or salinization), changes in rainfall regime resulting from land-atmosphere interactions (e.g., precipitation recycling, dust emissions), or changes in plant community composition (e.g., shrub encroachment, decrease in vegetation cover). We analyze each of these feedback mechanisms and discuss their possible enhancement by interactions with socio-economic drivers. Large scale effects of desertification include the emigration of "environmental refugees" displaced from degraded areas, climatic changes, and the alteration of global biogeochemical cycles resulting from the emission and long-range transport of fine mineral dust. Recent research has identified some possible early warning signs of desertification, which can be used as indicators of resilience loss and imminent shift to desert-like conditions. We conclude with a brief discussion on some desertification control strategies implemented in different regions around the world.

1. Introduction

Many dryland regions around the world are affected by rapid change in vegetation cover, plant community composition, hydrologic conditions, or soil properties, which results in an overall loss of ecosystem services and poses serious threats to sustainable livelihoods. The process underlying these changes is often termed "desertification". Depending on the driver and the geographic setting, desertification can result in an increase in bare soil (up to complete denudation of the soil surface), loss of soil resources (e.g., loss of nutrients, fine soil grains, and water holding capacity), increase in soil salinity and toxicity [119,169], or shifts in vegetation composition (e.g., from perennial to annual species, from palatable to unpalatable grasses, or from grassland to shrubland [187,205,215,224]). Desertification is commonly associated with changes that persist for several decades and are presumably permanent and irreversible, at least within the time scales of a few human generations.

The term "desertification" was first used by Lavauden [107] in the context of low rangeland productivity in poorly managed land in Tunisia [56]. However, this term is more commonly credited to Aubréville [11], who noted that forest clearing in West Africa caused erosion and land deterioration or "desertification". In both cases "desertification" was used to denote the outcome of a process of land degradation induced by human action and poor land management. Since then, several authors and agencies have provided their own definition of the problem. This has led in some cases to a sterile exercise that produced a myriad of definitions and generated confusion [228].

The United Nations adopted the definition of desertification as "land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities" [220]. Thus, the major difference with the earlier statements is that desertification can also result from climate change and not only from land mismanagement. The same definition was adopted by the Millennium Ecosystem Assessment [121]

* Corresponding author.
E-mail address: paolo@virginia.edu (P. D'Odorico).

0309-1708/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.advwatres.2012.01.013

with the clarification that "land degradation is in turn defined as the reduction or loss of biological or economic productivity of drylands". However, land degradation is not necessarily associated with a loss of ecosystem productivity. In Section 4.3 we will present some forms of desertification that may actually involve an increase in ecosystem productivity. The idea that desertification is associated with a persistent decrease in productivity contributes to the confusion existing around the issue of desertification and land degradation.

In recent years, the notion of desertification has been related to losses of ecosystem services resulting from the effect of anthropogenic disturbances and/or climate variations in dryland ecosystems. From this perspective desertification would be "a persistent reduction in the capacity of ecosystems to supply services… over extended periods" [121], and it would be "a result of long-term failure to balance demand and supply of ecosystem services in drylands" [121]. The major services rendered by dryland ecosystems are food security, carbon sequestration, supply of forage, fibers, wood and freshwater, maintenance of biodiversity, in addition to the recreational, cultural, and esthetic value of non-degraded dryland environments.

The view emerging from this discussion is that desertification is currently considered as the loss of the ability of a landscape to provide ecosystem services that are important to sustain life. It may result in a loss of biological and/or economic productivity, and in most cases it involves a persistent increase in bare soil at the expense of vegetation cover. Desertification does not necessarily occur at the desert margins: even dryland areas that are not at the edges of existing deserts may be prone to desertification [55].

In this paper we review some of the major mechanisms of desertification reported in different areas around the world. After a brief review of dryland hydrogeography and of current patterns of desertification (Sections 2 and 3), we analyze in detail theories of desertification based on the framework of bistable ecosystem dynamics (Section 4). Thus, we review the main feedback mechanisms of desertification (Section 4) and consider the major drivers of desertification, including climate change (Section 5), societal drivers (Section 6), soil salinization (Section 7) and rangeland degradation around watering points (Sections 8). We then discuss some environmental and human impacts of desertification (Sections 9 and 10). Because desertification may occur as a relatively abrupt process, land managers need some indicators of resilience loss and of the likelihood of an imminent shift to the desertified state. Therefore, we review some of the indicators that can be used as early warning signs of desertification (Section 11). Finally, we discuss some biophysical and socioeconomic measures for desertification mitigation and remediation (Section 12).

2. Hydrogeography of drylands

Drylands cover about 41% of the Earth's land surface and are home to about 35% of the global population [121]. Fig. 1a shows

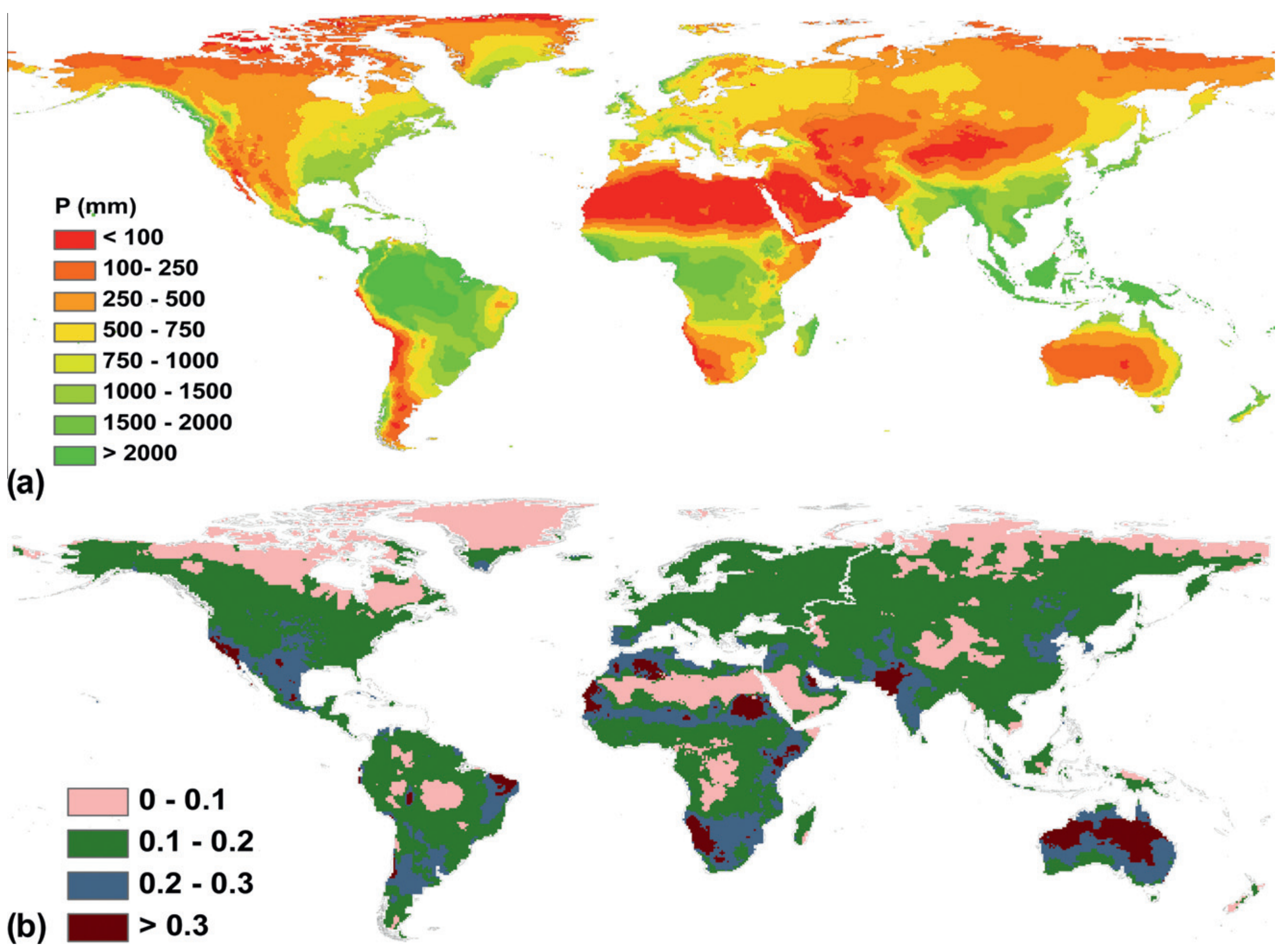

Fig. 1. (a) Global mean precipitation. (b) Coefficient of variation (NA refers to areas where no data were available). Based on the CRU TS 3.1 data, a gridded data set developed by the Tyndall Centre for Climate Change Research and the Climate Research Unit (CRU) of the University of West Anglia [125] interpolating station data with the anomaly approach [138,139]. The maps are based on data for the period 1901–2009, calculated for 0.5° by 0.5° grid.