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Desert dust hazards: A global review

N.J. Middleton

St Anne's College, University of Oxford, Oxford, OX2 6HS, UK

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ABSTRACT

Dust storms originate in many of the world's drylands and frequently present hazards to human society, both within the drylands themselves but also outside drylands due to long-range transport of aeolian sediments. Major sources of desert dust include the Sahara, the Middle East, central and eastern Asia, and parts of Australia, but dust-raising occurs all across the global drylands and, on occasion, beyond. Dust storms occur throughout the year and they vary in frequency and intensity over a number of time-scales. Long-range transport of desert dust typically takes place along seasonal transport paths. Desert dust hazards are here reviewed according to the three phases of the wind erosion system: where dust is entrained, during the transport phase, and on deposition. This paper presents a synthesis of these hazards. It draws on empirical examples in physical geography, medical geology and geomorphology to discuss case studies from all over the world and in various fields. These include accelerated soil erosion in agricultural zones – where dust storms represent a severe form of accelerated soil erosion – the health effects of air pollution caused by desert aerosols via their physical, chemical and biological properties, transport accidents caused by poor visibility during desert dust events, and impacts on electricity generation and distribution. Given the importance of desert dust as a hazard to human societies, it is surprising to note that there have been relatively few attempts to assess their impact in economic terms. Existing studies in this regard are also reviewed, but the wide range of impacts discussed in this paper indicates that desert dust storms deserve more attention in this respect.

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1. Introduction

Dust storms, most of which originate in the world's deserts and semi-deserts – commonly referred to as drylands – play an integral role in the Earth system (Goudie and Middleton, 2006; Shao et al., 2011). Their impacts are numerous and wide-ranging, including effects on climate processes and air chemistry, nutrient dynamics and biogeochemical cycling in both oceanic and terrestrial environments, soil characteristics and geomorphology. All of these impacts have repercussions for human society, of course, but

E-mail address: nicholas.middleton@st-annes.ox.ac.uk

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people are also influenced more directly by a number of desert dust hazards, such as atmospheric pollution. Given that drylands cover about 40% of the world's land surface and are home to more than 2 billion people (Safriel et al., 2005), these hazards are of considerable importance, but their significance is further magnified because desert dust events frequently involve long-range transport over thousands of kilometres, often taking dust far beyond dryland environments.

Our understanding of desert dust and our appreciation of its significance in the Earth system has increased markedly in recent years. In large part, this has been driven by self-interest due to the direct and indirect effects dust can have on human society. Indeed, over the last 100 years or so pulses of aeolian research output have occurred in response to major ecological disasters that have focused attention on wind erosion and blowing dust (Stout et al., 2009). We know that dust emissions vary in frequency and intensity seasonally and over longer timescales (Goudie and Middleton, 1992), responding to droughts (Middleton, 1985) and large-scale standing atmospheric pressure oscillations such as the North Atlantic Oscillation (Moulin et al., 1997), but the recent increase in dust storms in some areas (e.g. Kim, 2008; Ganor et al., 2010; Ghasem et al., 2012; Hsu et al., 2012; Notaro et al., 2015) prompted the United Nations General Assembly (UNGA) to adopt a resolution in 2015 entitled "Combatting sand and dust storms" (A/RES/70/195). This was followed in 2016 by the second UN Environment Assembly (UNEA-2) adopting a resolution that requests countries to address the challenges of sand and dust storms through relevant policy measures.

The purpose of this paper is to review the ways in which desert dust is related to hazardous conditions experienced by human populations both within drylands and beyond their margins. This synthesis of hazards research follows a brief resumé of our knowledge on the nature of desert dust storms, particularly their main sources areas, frequencies and long-distance transport pathways.

2. Desert dust

There are numerous sources of tropospheric aerosols, including sea salt, volcanic dust, cosmic dust and industrial pollutants, but this paper refers to mineral dust that originates from land surfaces. Most of this material comes from desert and semi-desert areas and is therefore commonly referred to as desert dust. Dust storms are atmospheric events typically associated with drylands because of the preponderance of desiccated, unconsolidated substrates with little vegetation cover. Strong, turbulent winds blowing over desert surfaces raise fine-grained material, much of it consisting of silt-sized (4–62.5 μm) and clay-sized (<4 μm) particles, to reduce visibility to less than 1 km (Fig. 1). Atmospheric PM_{10} dust concentrations exceed 15,000 μg/m^3 in severe events (Leys et al., 2011), although concentrations naturally diminish with distance from source areas as material in suspension is deposited downwind by wet and dry processes. Desert dust is dominated by SiO_2 and Al_2O_3, but may also contain significant proportions of Fe_2O_3, CaO and MgO. Many desert dust source areas also contribute a large salt content, organics content, pathogens and anthropogenic pollutants.

2.1. Source areas

Not all drylands are equally active from a dust storm perspective. Analyses of data from terrestrial meteorological stations and a number of satellite borne sensors has provided us with a decent, though not perfect, understanding of where the planet's major contemporary desert dust sources are located (Ginoux et al., 2012; Washington et al., 2003), although these surveys omit most high-latitude sources (Bullard et al., 2016). The Sahara is undoubtedly the largest source of atmospheric desert dust, contributing perhaps 50% of the global total, followed by China and Central Asia (about 20% of the global total), Arabia and Australia. Drylands in Southern Africa and the Americas are relatively minor sources, together accounting for probably less than 5% of the global total. These regional proportions are by necessity tentative because quantifying the global mineral dust mass budget is not a straightforward matter. Since actual measurements are geographically sparse and temporally sporadic, the majority of estimates are produced using models. Most estimates of total mineral dust emissions to the global atmosphere range between one billion and three billion tonnes per annum (e.g. Mahowald et al. (1999), Miller et al. (2004)). The lack of agreement between models is largely a reflection of the fact that there remains much to learn about dust emission and transport processes (Cakmur et al., 2006; Evan et al., 2014).

Fig. 1. Sydney harbour bridge obscured by thick dust during the notorious Red Dawn event in Australia in September 2009 (Photo: Mrcricket48).

Within dryland regions, certain types of geomorphology are typically richer in dust-sized material than others (Bullard et al., 2011). Water plays a particularly important role in providing dust-producing desert surfaces such as large basins of internal drainage (e.g. Bodélé, Taoudenni, Seistan, Eyre), alluvial deposits, playas and piedmont alluvial fans. These and a number of other typically abundant sources of desert dust are shown with regional examples in Table 1. Dust is deflated from these sources with a marked seasonality. The Bodélé Depression produces most of its dust during a season lasting from October to April, affecting much of West Africa with the Harmattan dust haze. In the Middle East,

Table 1
Geomorphological units from which substantial dust deflation occurs.

Geomorphological unit	Regional example	References
Floodplain	Lower Mesopotamia, Iraq	Al-Dousari and Al-Awadhi (2012)
Dry river bed (wadi)	Patagonia, Argentina	Johnson et al. (2010)
Alluvial fan	Hexi Corridor, China	Derbyshire et al. (1998)
Salt pan	Mojave Desert, USA	Reynolds et al. (2007)
Palaeolake bed	Bodélé Depression, Chad	Bristow et al. (2009)
Ephemeral lake bed	Hamoun Basin, Iran/ Afghanistan	Rashki et al. (2013)
Active dunes	Erg in Koussamene, Mali	Coudé-Gaussen (1989)
Devegetated fossil dunes	Lake Eyre Basin, Australia	Bullard et al. (2008)
Glacial outwash plain	Sandar plains, southern Iceland	Prospero et al. (2012)
Loess	Loess Plateau, China	Park and In (2003)