Dust Storms and Human Health

Andrew S. Goudie

Abstract Dust storms play a pervasive role in the Earth system. They are events of considerable extent and of frequent occurrence in drylands. The amount of suspended material they contain is an important aspect of dust storms in relationship to health. They transport particulates, pollutants and biological materials for long distances downwind. In some parts of the world, though not all, they appear to be occurring with greater frequency, and some forecasts suggest that this will continue in response to increasing land-use pressures and lower soil moisture contents resulting from climate change. Studies, particularly in east Asia, show associations between dust events and a range of human health issues, including respiratory problems, cardiovascular complaints, meningococcal meningitis, coccidioidomycosis, conjunctivitis, skin irritation, measles, and transport accidents.

Keywords Dust storms · Health · Respiratory · Cardiovascular · Source areas · Particulates

1 Introduction

This chapter reviews recent studies of dust storms (e.g. their sources areas, frequencies and particulate contents) and considers the evidence that is accumulating to relate these characteristics to health disorders. This issue has already been reviewed by Zhang et al. (2016).

Dust storms play a pervasive role in the Earth system (Goudie and Middleton 2006; UNEP et al. 2016). They result from fronts and convective *haboobs*, which raise dust from desert surfaces. In severe events, dust may reach concentrations in excess of 6000 μg m^{-3} (Goudie 2014). Much of this load consists of silt. It can be transported over thousands of kilometers and is deposited downwind. The silt comes finer with distance from source. It is dominated by SiO_2 and Al_2O_3, but it may also have a large salt content, an organic component, and crucially from the health point of view, can transport pathogens and anthropogenic pollutants. For example, dust

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from China, collected in Japan, absorbs anthropogenic atmospheric pollutants during transport. Consequently, Asian Dust Events (ADEs) in Japan coincide with increases in hospital admissions and clinical visits for allergic diseases such as asthma, allergic rhinitis and conjunctivitis (Otani et al. 2017). Dust storms can also carry potentially carcinogenic fibrous clay called palygorskite (Rodriguez-Navarro et al. 2018).

1.1 Source Areas

The health impacts of dust storms depend on where humans live with respect to dust sources and the downwind direction of dust transport from them. Satellite sensors have demonstrated the primacy of arid regions and of basins of internal drainage and of alluvial deposits. Estimates of the relative strength of dust emissions demonstrate the importance, firstly of the Sahara (with over half of the global total), secondly of China and Central Asia (with about 20%), thirdly of Arabia and fourthly of Australia. Southern Africa and the Americas are minor sources, together accounting for less than about 5% of the total. Some dust is raised from high-latitude areas.

Saharan dust is moved by the trades toward the Gulf of Guinea, producing Harmattan haze. It is also carried to the Near East, the Arctic, across the Atlantic to the Americas (Prospero et al. 2014), and to the countries bordering the Mediterranean.

In China, dust storms cover immense areas, particularly in the arid west and transport particulates to its more humid parts, Korea, Japan and beyond. As a consequence, some mega-cities, including Beijing, Shanghai, Seoul, Tokyo and Taipei are subjected to ADEs. Dust is also generated in Mongolia, where mining activity has increased its prevalence.

Dust storms in the Middle East occur on the plains of Iraq and Kuwait and have possible health implications (Al-Hemoud et al. 2018). Much dust is lofted off the Tigris-Euphrates alluvial plain, the Jaz Murian depression and the Seistan Basin. In Tehran, the great bulk of particulates are derived from the deserts of Iraq and Syria (Givehchi et al. 2013), while some dust in the United Arab Emirates may be derived from Iran and central Asia. The Tokar Delta in Sudan emits dust over the Red Sea—dust which moves into Arabia and degrades air quality. In India, the greatest number of dust storms occur in the Thar, but eastward-moving dust clouds cross heavily populated North India. In the southern former Soviet Union, dust is blown off the desiccated bed of the Aral Sea and there are many dust storms in Kazakhstan (Issanova et al. 2015).

In southern Africa, Etosha Pan, the Namib river valleys and the Mkgadikgadi Depression (Vickery et al. 2013) are big sources. In South America, the exposed bed of the desiccating Mar Chiquita (Argentina) is a major source (Bucher and Stein, 2016). Dust is also generated from Patagonia, and the Puna and Altiplano. In the USA, dust storms occur in the arid west and material blown from the anthropogenically desiccated Owens Lake has caused health concerns. Australia, though not as dusty as some regions of the world, is the largest source in the Southern Hemisphere. Australian dust causes respiratory problems in New Zealand (Cowie et al. 2010) and impacts upon air quality in Brisbane, Sydney, Newcastle and Melbourne (Leys et al. 2011).

1.2 The Changing Frequency of Dust Storms

Dust storm frequency is important in health terms. Analysis of meteorological data has revealed the changing frequency of events for the last six decades or so. Some areas have shown increasing trends (e.g. the Sahel of Africa and the eastern Gobi of Mongolia). However, others have shown declining trends in the late twentieth century (e.g. China, the Canary Islands, Turkmenistan, Central Asia, Pakistan). In Australia, the declining trend was followed by a spike of activity in the early years of the present century-‘the Millennium Drought’ (O’Loingsigh et al. 2017). Other areas (e.g. the Kalahari and Seistan) have shown marked fluctuations upwards and downwards in response to such factors as lake flooding and desiccation (Rashki et al. 2015) or climatic fluctuations. In China, both natural and anthropogenic factors are implicated in the observed trends. There is certainly no clear upward trend in dust storm activity in China or Korea (Wang et al. 2018) though the early years of the present millennium saw some severe events (Kurosaki et al. 2011).

Mahowald et al. (2010) have estimated the global picture of changes in dust storm activity for the twentieth century. They suggest that a doubling of atmospheric desert dust loadings took place over much of the globe.

1.3 PM_{10} and $PM_{2.5}$ Levels in Dust Storms

The amount of suspended material they contain is an important aspect of dust storms in relationship to health and in some parts of the world, such as the Negev, dust concentrations are increasing (Krasnov et al. 2016). Concentrations are normally expressed as PM_{10} and $PM_{2.5}$ values. Some storms close to source are associated with very high concentrations, but it is notable that concentrations at large distances downwind can also be elevated, as is evident for some of the big cities in East Asia (Wang et al. 2013) and Australia (Leys et al. 2011). Even in southern Europe and the Caribbean, African dust incursions can produce high particulate levels (Prospero et al. 2014).

According to WHO, the acceptable annual mean value of PM_{10} is 20 $\mu g\ m^{-3}$ and the acceptable 24 h mean value is 50 $\mu g\ m^{-3}$ (de Longueville et al. 2013). The U.S. Environmental Protection Agency regards 24 h $PM_{2.5}$ levels between 35.5 and 55.4 $\mu g\ m^{-3}$ as being unhealthy for sensitive groups, 55.5–150.4 as being unhealthy, 150.5–250.4 as being very unhealthy, and 250.4–500 as hazardous. These values are regularly exceeded in dust storms (Goudie 2014; Middleton 2017). PM_{10} values may remain high for extended periods, particularly in some Iranian sites (Goudarzi et al. 2017). Engelbrecht et al. (2009) showed that over large parts of the Middle East people were exposed to average annual PM_{10} values ranging from 72 to 303 μg m^{-3} and $PM_{2.5}$ values ranging from 35 to 111 μg m^{-3}.

1.4 Biomaterials

Dust storms pick up and transport bacteria, pollen spores, fungi and viruses (Weil et al. 2017). These have implications for disease incidence, including meningococcal meningitis and coccidiomycosis. Desert dust may contain dangerous cyanotoxins (Richer et al. 2015). In Japan, Watanabe et al. (2011) found that asthma in adults was augmented on days when Asian Dust carried pollen in comparison with dusty days without pollen. El-Askary et al. (2017) suggested that Kawasaki Disease (KD), a rare vascular disease that can result in cardiac damage in children, could be associated with a fungus known as *Candida*, which is transported in dust from China to Japan.

1.5 Miscellaneous Pollutants

Dust storms pick up and transport anthropogenic materials such as pesticides, herbicides, heavy metals, dioxins and radioactive isotopes. Those that have moved across heavily industrialized and polluted areas, such as northern China, may therefore pose a greater risk than those storms that have passed over less heavily developed areas (Almeida-Silva et al. 2013). In addition, dust storms remove toxic materials, including arsenic, from desiccated lake beds and some dune areas (Soukup et al. 2012; Morman and Plumlee 2013). There has been especial concern about the deflation of pesticides, including Lindane, from the exposed bed of the Aral Sea (Balmagambetova et al. 2017). Radionuclides may be blown from sites of past nuclear tests and from uranium mines tailings (Csavina et al. 2012).

2 Human Health Disorders

As Sandstrom and Forsberg (2008) have pointed out, particle size is a main determinant of where in the respiratory tract a dust particle will come to rest when inhaled. Because of their small size, particles on the order of ~10 μ or less (PM_{10}) can penetrate the deepest part of the lungs such as the bronchioles or alveoli. Larger particles are generally filtered in the nose and throat via cilia and mucus. Particles which are <2.5 μ penetrate into the gas exchange regions of the lung, and ultra-fine particles (<100 nm) may pass through the lungs to affect other organs, with possible cardiovascular consequences (Martinelli et al. 2013).

2.1 Respiratory Disorders

The pathogenic effect of dust inhalation on respiratory tissues can be attributed to the direct physical action of dust particles on the epithelium of the human airways and may be exacerbated by the toxic effects of both trace elements (including arsenic) and of biologically active compounds (Schweitzer et al. 2018). Studies in East Asia have related ADEs to asthma, pneumonia and tracheitis (Yang 2013). Tao et al. (2012), working in Lanzhou, China, found that dust storms led to increased respiratory hospitalizations, particularly for those aged >65. Tam et al. (2012), working in Hong Kong, found significant increases in emergency hospital admissions due to respiratory problems, with a 1.05% increase per 10 $\mu g\ m^{-3}$. Chien et al. (2012), working in Taipei, found that compared with weeks before ADEs respiratory clinic visits during the weeks after an event increased by 2.5% for children younger than 6, and by 5.0% for children aged 7–14. It poses a particular risk to the elderly (Lin et al. 2016). Studies in Seoul, Korea, by Lee and Lee (2013) showed that ADEs led to a 22% increase in the rate of asthma treatments with a 6-day lag. Pneumonia and allergic rhinitis are respiratory complaints that appears to be influenced by ADEs in Taiwan (Kang et al. 2012).

In Australia, dust blowing from the interior is significantly associated with asthma severity. A 15% increase in non-accidental mortality at a lag of 3 days from a dust event was found for Sydney (Johnston et al. 2011), where Merrifield et al. (2013) also found large increases in asthma emergency department visits.

The effects of African dust outbreaks on asthma and other respiratory and cardiac afflictions in southern Europe has been noted (Stafoggia et al. 2016), and there is now a large corpus of work on the particulate loads associated with African dust incursions, and the effects that these have on respiratory diseases (see, e.g., Trianti et al. (2017) on Greece and Díaz et al. (2017) on Spain).

Other locations where a link between dust events and respiratory problems has been established include Seistan and other parts of Iran (Khaniabadi et al. 2017). There are also high levels of asthma in Arabia, with, for example, 24% of the population of Saudi Arabia being asthmatic, and dust storms are one possible factor (along with lifestyle, smoking and indoor dust levels) (Al-Ghazawy 2013). On the other hand, a significant association between dust levels and respiratory mortality has not always been found (Zhang et al. 2016).

Much dust storm material is silt-sized quartz, and if this is inhaled over a sustained period, it causes non-occupational silicosis in some areas of High Asia. Silicosis may be a factor in the prevalence of tuberculosis in the Thar (Mathur and Choudhary 1997). In the 'dust belt' of North Africa to China, a substantial proportion of lung cancers may be caused by exposure to the $PM_{2.5}$ particles in desert dust (Giannadaki et al. 2014), especially in countries like Mauritania and Mali.

2.2 Cardiovascular Disorders

High particulate levels in the air cause cardiovascular disease, including myocardial infarction, stroke, heart failure, arrhythmias, and venous thromboembolism (Martinelli et al. 2013). Kang et al. (2013), working in Taiwan, found that ADEs were associated with an acute increase in stroke hospitalization, while Liu et al. (2017) presented data which indicated that $PM_{2.5}$ concentrations from ADEs in Taiwan were highly correlated with emergency visits for cardiovascular diseases. However, also working in Taiwan, Yang et al. (2009) were unable to find a statistically significant association with congestive heart failure. In Nagasaki, Japan, Ueda et al. (2012) reported that heavy ADEs caused emergency ambulance dispatches for cardiovascular diseases to rise by 20.8%. Likewise, in Cyprus, Middleton et al. (2008) found that cardiovascular admissions increased after dust episodes, and Neophytou et al. (2013) found there was a 2.4% increase in daily cardiovascular associated with each 10 ug m^{-3} increase in PM_{10} concentrations on African Dust days. In Spain, Perez et al. (2012) found an increased cardiovascular mortality associated with $PM_{10\text{-}2.5}$ levels, as did Alessandrini et al. (2013) in Rome, Italy. In Israel, Vodonos et al. (2014) found a strong correlation between PM_{10} concentrations and chronic obstructive pulmonary disease (COPD). In the USA, Crooks et al. (2016) found a positive association between dust storms and non-accidental, cardiovascular, and other non-accidental mortality, particularly in the two states with the highest dust storm incidence, Arizona and California.

2.3 Measles

Although little work has been undertaken, Ma et al. (2017) found an association between dust events and measles incidence in the Gansu region of China. The Dust Bowl years of the 1930s were a time of great measles epidemics in Kansas, USA (Brown et al. 1935). The causes of this association need further investigation.

2.4 Miscellaneous Other Diseases and Health Issues

2.4.1 Coccidioidomycosis

Coccidioidomycosis, an infection caused by inhalation of airborne spores of soil-dwelling fungi found in the south-west USA and parts of Mexico and central and South America, can affect the lungs, cause extreme disfigurement, and be fatal (Gorris et al. 2018). In the USA, it is known as Valley Fever. Around 150,000 cases are reported annually (Anderson 2013). There is a strong bimodal seasonality of the disease in Arizona, with peaks in the drier and dusty months of June–July and

August–November. Tong et al. (2017) have found that in the American south-west, the frequency of windblown dust storms has increased 240% from 1990s to 2000s. This trend is associated with variations of sea surface temperature caused by the Pacific Decadal Oscillation. They found that the frequency of dust storms is correlated with Valley Fever incidences, and that the infection rate went up more than 800% from 2000 to 2011. Disturbance of desert surfaces in California is exacerbating the problem (Gorris et al. 2018) by increasing the probability of aerosolizing *Coccidioides* spp. spores.

2.4.2 Meningococcal Meningitis

Meningococcal meningitis is a serious problem in West Africa (Thomson et al. 2009). For instance, during the 2017 epidemic in northern Nigeria, 14,473 cases (including 1158 deaths) were reported, of which over 50% involved children under the age of 16. There is a clear temporal correlation between times of great atmospheric dust contents (the Harmattan) and cases of meningitis (Deroubaix et al. 2013). One theory is that dust, combined with extremely dry air, damages the pharyngeal mucosa, thereby easing bacterial invasion. Attempts at vaccination are a major priority.

2.4.3 Conjunctivitis

Prolonged exposure to dusty air can lead to conjunctivitis. Chien et al. (2014) found elevated conjunctivitis clinic visits during dust storm periods, particularly for children. Ko et al. (2016) also found a link between ADEs and conjunctivitis in Japan.

2.4.4 Dermatological Disorders

The presence of heavy metals such as nickel in dust may cause skin irritation (Onishi et al. 2015). In addition, it has been suggested that ADE particles can 'exert toxicological effects on human skin through the activation of the cellular detoxification system, the production of pro-inflammatory and immunomodulatory cytokines and changes in the expression of proteins essential in normal epidermal differentiation' (Choi et al. 2011, p. 92).

2.4.5 Algal Blooms

The nutrients carried in dust storms, including iron (Mahowald et al. 2009), can indirectly impact human health by stimulating chlorophyll production and toxic algal blooms in coastal environments (Gallisai et al. 2016). These have a range of effects including shellfish poisoning and respiratory complaints (Fleming et al. 2011).

2.4.6 Transport Accidents

Dust storms cause death through their role in causing road and air accidents (Baddock et al. 2013). Some fatal commercial air crashes have been attributed to visibility reduction or to the adverse mechanical effects of dust storms.

3 Conclusions

Dust storms are events of considerable extent and of frequent occurrence in deserts and on their margins. They transport particulates, pollutants and biological materials for long distances downwind. In some parts of the world, though not all, they appear to be occurring with greater frequency and some forecasts suggest that this will continue in response to increasing land-use pressures and lower soil moisture contents resulting from climate change. An increasing corpus of studies, particularly in east Asia, show associations between dust events and a range of human health issues, including respiratory problems, cardiovascular complaints, meningococcal meningitis, conjunctivitis, skin irritation, measles and transport accidents. It is probable that some groups of people may be especially susceptible to these effects, including the elderly, those who are socio-economically disadvantaged (Ho et al. 2018) and the very young (Foreman 2018). Plainly, dust storm control and mitigation are of immense importance (Middleton and Kang 2017).

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