Science of the Total Environment 487 (2014) 82–90

Contents lists available at ScienceDirect

Science of the Total Environment

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

Effect of wind speed and relative humidity on atmospheric dust concentrations in semi-arid climates

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HIGHLIGHTS

- Relative humidity and wind speed are determinants of atmospheric dust concentrations.
- Humidity must be considered in dust emission predictions in semi-arid regions.
- At high wind speeds, PM_{10} has a maximum with relative humidity.

ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 31 March 2014
Accepted 31 March 2014
Available online xxxx

Editor: P. Kassomenos

Keywords:
Dust emission
Relative humidity
Wind speed
Semi-arid
PM_{10}

ABSTRACT

Atmospheric particulate have deleterious impacts on human health. Predicting dust and aerosol emission and transport would be helpful to reduce harmful impacts but, despite numerous studies, prediction of dust events and contaminant transport in dust remains challenging. In this work, we show that relative humidity and wind speed are both determinants in atmospheric dust concentration. Observations of atmospheric dust concentrations in Green Valley, AZ, USA, and Juárez, Chihuahua, México, show that PM_{10} concentrations are not directly correlated with wind speed or relative humidity separately. However, selecting the data for high wind speeds (>4 m/s at 10 m elevation), a definite trend is observed between dust concentration and relative humidity: dust concentration increases with relative humidity, reaching a maximum around 25% and it subsequently decreases with relative humidity. Models for dust storm forecasting may be improved by utilizing atmospheric humidity and wind speed as main drivers for dust generation and transport.

1. Introduction

Dust storms have been shown to have deleterious impacts to human health. When near-zero visibility occurs during these events, serious traffic accidents have claimed numerous lives and shut down entire highways for extended periods of time (Novlan et al., 2007). The mere presence of dust in breathed air can have negative impacts on the human respiratory and cardiovascular systems (Schwartz, 1993; Pope et al., 1995; Peters et al., 1997; Donaldson et al., 2001; Ghio and Devlin, 2001). Additionally, spores and contaminants associated with dust and aerosol can adversely impact human health, causing a range of issues from respiratory infections to toxic exposure (Low et al., 2006; Quintero et al., 2010; Csavina et al., 2011; Degobbi et al., 2011). In particular, the transport of metals and metalloids in atmospheric dust around mining operations may lead to increased human exposure to toxic contaminants such as arsenic, lead and cadmium (Csavina et al., 2011, 2012).

In arid and semi-arid climates, dust storms are common. In El Paso, TX, alone, Novlan et al. (2007) reported that an average of 14.5 significant dust events (i.e. blowing dust leading to visibility reductions of 6 miles or less for duration of 2 h or more) have occurred annually since 1932. These dust events are predicted to increase in occurrence in the US Southwest due to warmer and drier conditions from climate change and therefore are becoming an increasingly studied phenomenon (IPCC — International Panel for Climate Change, 2007; Breshears et al., 2012).

Dust events are caused by local and regional aeolian erosion. Wind speed is a primary factor in dust generation with vegetation cover and soil structure also playing significant roles (Zobeck and Fryrear, 1986;

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http://dx.doi.org/10.1016/j.scitotenv.2014.03.138

Zobeck, 1991; Yin et al., 2007). Wind tunnel studies have shown that threshold velocity for aeolian erosion is dependent on atmospheric humidity due to its impact on soil surface moisture content which, in turn, affects interparticle cohesion (Ravi et al., 2004, 2006; Neuman and Sanderson, 2008). Temperature has also been found to correlate with dust concentrations (Hussein et al., 2006). Yet, despite the many studies on the wind erosion of soils, prediction of dust events is still a significant challenge (Desouza et al., 2010).

A growing body of research is showing the importance of relative humidity on dust emissions and, consequently, atmospheric dust levels (Ravi et al., 2004; Ravi and D'Odorico, 2005; Karar and Gupta, 2006; Ravi et al., 2006; Shah et al., 2006; Vassilakos et al., 2007; Giri et al., 2008; Neuman and Sanderson, 2008). Ravi et al. (2004) found that the threshold friction velocity for dust emissions was positively correlated with relative humidity. However, later studies found opposite trends at high relative humidity (>40%) when temperature was relatively constant (Ravi and D'Odorico, 2005; Ravi et al., 2006).

At low air relative humidity (RH < 40%), water content in soil particles at equilibrium with atmospheric air occurs as single-layer adsorption (Neuman and Sanderson, 2008). This water layer interferes with interparticle forces: in some cases, the threshold friction velocity decreases with an increase in water content, since the adsorbed water layer decreases particle cohesion. This effect was found to be the controlling factor in emission experiments performed with various types of sand in a wind tunnel set-up by Ravi et al. (2004). However, in the same range of relative humidity, the water layer might increase cohesion in which case an increase in threshold velocity with relative humidity is observed. This type of effect was reported by Neuman and Sanderson (2008) in wind tunnel experiments with simulated soils made up of approximately monodisperse sand and glass beads. The opposite effects of an adsorbed single water layer and a multilayer liquid film suggest that dust emission is not completely determined by ambient humidity and wind speeds, but other factors that affect particle cohesion, such as surface roughness and chemical composition, might play an important role in low humidity environments. At high relative humidity (RH > 40%), multiple adsorbed water layers exist and eventually liquid films and bridges (RH > 60%) form, which invariably increase soil particle cohesion. In this regime, an increase in relative humidity leads to an increase in threshold friction velocity. Changes in the threshold velocity lead to changes in dust emission fluxes and, consequently, atmospheric particulate concentrations.

In this study, we examine dust events in two semi-arid sites: Green Valley, AZ, USA (average annual precipitation 11.3 in.), and Juárez, Chihuahua, Mexico (average annual precipitation 10.5 in.). During the spring months of March–May, dust storms are a common occurrence in these locations. Dust was sampled at six field locations, ranging in soil and vegetation cover, in the region of Green Valley and two locations in Juárez. In addition, PM_x and meteorological data from the Pima Department of Environmental Quality (PDEQ) in Arizona were analyzed for longer term trends. We hypothesize that both wind speed and relative humidity may play an important role in observed atmospheric dust concentrations. In particular, the effect of relative humidity on dust emission rates should have a bearing on atmospheric dust.

2. Materials and methods

2.1. Green Valley study

Green Valley (lat. 31° 52′ 16″, long. −110° 59′ 24″) is a unique location because it is impacted by regional dust sources from mining operations, including ore extraction and mine tailings, and it is proximate to the Santa Rita Experimental Range (a long-term ecological research station for semi-arid grasslands.) Green Valley is predominantly a retirement community so that the region has a large population of elderly people who may be especially sensitive to particulate inhalation health effects (Donaldson et al., 2001). Fig. 1 shows six sampling locations chosen for the study of wind events in the period March–May, 2011. The southernmost mine tailings seen on the map are inactive and contain negligible concentrations of toxic species, such as As, Pb and Cd. The

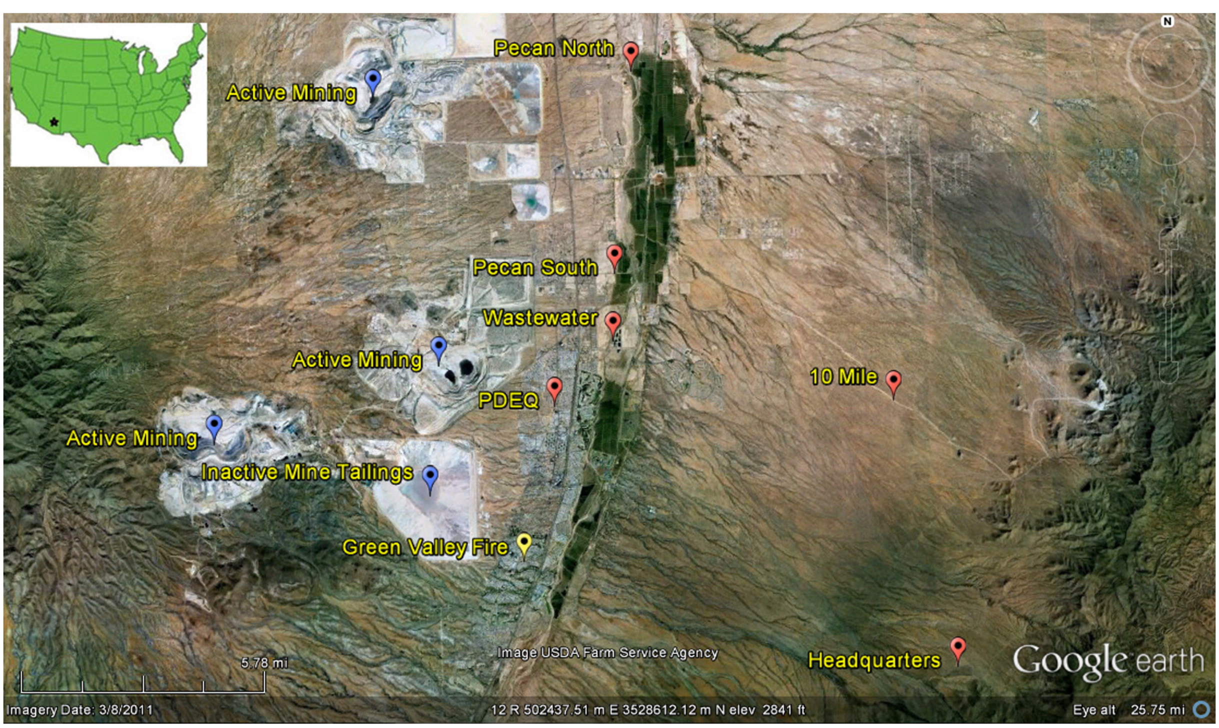

Fig. 1. Field locations for dust monitoring in Green Valley, AZ, USA. Pecan North and Pecan South are located on the edge of a pecan tree grove and beside a dry river bed; Wastewater is located beside the same river bed; PDEQ represents an urban sample; 10 Mile is approximately 10 miles (16 km) from mining activities; HQ (Santa Rita Experimental Range) represents a natural background site chosen for the region. Annual data were taken from Green Valley Fire. Mining activities for the region are labeled in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)