



Dryness of ephemeral lakes and consequences for dust activity: The case of the Hamoun drainage basin, southeastern Iran



A. Rashki^a, D.G. Kaskaoutis^{b,*}, A.S. Goudie^c, R.A. Kahn^d

^a Natural Resources and Environment College, Ferdowsi University of Mashhad, Mashhad, Iran

^b Department of Physics, School of Natural Sciences, Shiv Nadar University, Dadri, 203207, India

^c China Centre, University of Oxford, 74 Woodstock Road, Oxford, OX2 6HP, UK

^d NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA

HIGHLIGHTS

- Understanding the role of Land Use.
- Land Cover changes and precipitation variability in dust emissions over Sistan, Iran.
- Effect of dryness of ephemeral lakes on dust storm activity, visibility and aerosol loading.
- Effect of dryness of ephemeral lakes on land-atmosphere fluxes.
- Satellite monitoring of variability in lakes surface.

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ABSTRACT

This study examines the influence of changes in the water coverage in the Hamoun dry-bed lakes on visibility, dust outbreaks, aerosol loading and land-atmospheric fluxes over the region covering the period 1985–2005. The Hamoun basin, located on the southeastern Iran and western Afghanistan borders, has been recognized as one of the major dust source regions in south Asia and is covered by shallow, marshy lakes that are fed by the Helmand and Farahrood rivers. When the water in watersheds that support the lakes is drawn down for natural or human-induced reasons, the end result is a decrease in the water coverage in the basin, or even complete dryness as occurred in 2001. Then, strong seasonal winds, mainly in summer, blow fine sand and silt off the exposed lakebed, enhancing dust activity and aerosol loading over the region. Satellite (Landsat) and meteorological observations reveal that the water levels in the Hamoun lakes exhibit considerable inter-annual variability during the period 1985–2005 strongly related to anomalies in precipitation. This is the trigger for concurrent changes in the frequency of the dusty days, aerosol loading and deterioration of visibility over the region, as satellite (TOMS, MODIS, MISR) observations reveal. On the other hand, soil moisture and latent heat, obtained via model (GLDAS_noah-10) simulations are directly linked with water levels and precipitation over the region. The desiccation of the Hamoun lakes in certain years and the consequent increase in frequency and intensity of dust storms are serious concerns for the regional climate, ecosystems and human health.

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1. Introduction

Dust storms are natural hazards that affect weather, climate, human health and ecosystems for short-time intervals ranging from a few hours to a few days. Numerous studies have been conducted over the globe with different instrumentation and techniques focusing on the investigation of such phenomena (e.g. Goudie and Middleton, 2001; Akhlaq et al., 2012). Desert dust is a major component of tropospheric aerosols, with global flux estimates of 1500 to 2600 Tg yr^{-1} (IPCC,

2007), playing a vital role in attenuation of solar radiation, marine environment fertilization, atmospheric heating and dynamics (e.g. Tegen et al., 1996; Dunion and Velden, 2004; Prasad et al., 2007; Singh et al., 2008; Patadia et al., 2009; Hansell et al., 2010, 2012; Valenzuela et al., 2012). Furthermore, dust deposition adds exogenous mineral and organic material to terrestrial surfaces, thereby having a significant impact on the Earth's ecosystems and biogeochemical cycles (Mahowald et al., 2005; Lawrence and Neff, 2009). Prospero et al. (2002) noted that the major desert-dust sources over the globe are associated with arid (annual precipitation below 200 mm) topographic low areas into which water transports alluvial material, thus providing a source of soil particles that are easily eroded by the wind.

* Corresponding author. Tel.: +91 7503037241.

E-mail address: dimitriskask@hotmail.com (D.G. Kaskaoutis).

Land use–land cover (LULC) changes are linked to global climate change and several other environmental issues concerning land–atmosphere interactions, deforestation and desertification (Brooks and Legrand, 2000). In this respect, changes in the natural inundation of permanent and ephemeral lakes within arid/desert environments may lead to significant fluctuations in regional dust loading on seasonal to inter-annual time-scales (Mahowald et al., 2003). Under prolonged dry conditions, arid-land surfaces that were previously wet or stabilized by vegetation are increasingly susceptible to deflation by wind, resulting in desertification and increased dust outbreaks (Goudie and Middleton, 2006). Thus, airborne dust may originate from dried lake beds, can be highly saline, and the fine particles can be injurious to health (Karanasiou et al., 2012). Desiccation of lake beds due to drought or to water diversion schemes, observed in the Aral Sea in Uzbekistan (Breckle et al., 2012), Bodélé depression in Chad (Koren et al., 2006), Owens Lake in California (Reheis et al., 2009), salt lakes (Chotts) in Algeria and Etosha Pan in Namibia (Mahowald et al., 2003), Lake Eyre in Australia (Baddock et al., 2009), and the Hamoun lakes in Iran (Rashki et al., 2012, 2013a,b), can lead to increased dust-storm activity. Previous studies (Bryant, 1999; Bryant and Rainey, 2002) using remote sensing techniques have shown that closed basins containing ephemeral lakes are the most sensitive areas to regional changes in rainfall patterns.

The Hamoun basin, located on the Iran-Afghanistan border, has attracted scientific interest during recent years, since it constitutes a major dust source region in southwest Asia, often producing intense dust storms that cover the Sistan region of eastern Iran, southwest Afghanistan and Pakistan (Goudie and Middleton, 2006; Alam et al., 2011; Rashki et al., 2012, 2013b). The lakes' desiccation has created the largest source of dust-related PM₁₀ at a regional scale with maximum values usually $> 1000 \mu\text{g m}^{-3}$ during dust storms (Rashki et al., 2012); the sand and dust particles are swirled into huge dunes that may cover a hundred or more villages along the former lake (Sharifikia, 2013). Dust particles also cover farms and grasslands, resulting in damage to crops and filling rivers and water channels with aeolian material. In recent years, tens of thousands of people have suffered from respiratory diseases and asthma during months with devastating dust storms in the Sistan region, especially in the cities of Zabol and Zahak and the surrounding villages (Selinus et al., 2010). According to the Asthma Mortality Map of Iran, the rate of asthma in Sistan is, in general, higher than in other regions (Selinus et al., 2010). Miri et al. (2007) showed that 63% of the people in Zabol suffer from respiratory diseases, whereas the health damage and medical costs for patients exceeded 166.7 million U.S. Dollars during the period 1999–2004.

The primary objective of the present work is to assess LULC changes in the Hamoun drainage basin during the period 1985–2005 and to evaluate the fluctuations in dust-storm activity, visibility, aerosol loading as well as surface characteristics (soil moisture) and land–atmosphere fluxes (latent heat). Moreover, it aims to assess the influence of ephemeral lake desiccation on seasonal and inter-annual dust emissions and the contribution of the Hamoun dry-bed lakes to dust loading over the Sistan region. A synergy of Landsat satellite imagery with data from the Zabol meteorological station, observations from MODIS, MISR and TOMS satellite sensors and model (GLDAS_noah-10) simulations was used. Recently, Sharifikia (2013) highlighted by means of Landsat images the drought conditions in the Hamoun dry-bed lakes during the last decade as a natural hazard, focusing mainly on the drought effects on the local economy and ecosystems, crop failure, health problems and salty-soil movement over the inhabited areas and agricultural fields. The present work further associates the water level in the Hamoun basin with precipitation, dust outflows and aerosol loading, and examines the influence of dryness in the Hamoun lakes on visibility records, dusty days, and land–atmosphere fluxes over the region.

2. Study region

The Sistan region is located in southeastern Iran close to the Iranian borders with Pakistan and Afghanistan (Fig. 1) and its climatic conditions are fully described elsewhere (Moghadamnia et al., 2009; Rashki et al., 2012, 2013a,b). The area has more than 400,000 people and the major cities are Zabol and Zahak. The most important meteorology-atmospheric phenomenon over the region that controls the dust activity, air quality and human health is the Levar northerly wind, commonly known as the “120-day wind”, which causes frequent dust and sand storms, especially during June–August. This renders Sistan one of the windiest deserts in the world. The northern edge of the Sistan region is the topographically low Hamoun basin, which is a depression that receives the discharge from the Helmand (Hirmand) river and its tributaries (Fig. 1). It is a large and remote desert basin, extremely arid and known for its windstorms, extreme floods and droughts. Most of the Hamoun watershed (~90%) is located in Afghanistan and practically all of the wetlands' water sources originate there. The Iranian part is arid, rocky terrain that produces runoff only in rare cases of significant local rainfall. The Hamoun lakes complex (Hamoun-e-Puzak, Hamoun-e-Sabori, Hamoun-e-Hirmand and Baringak) (Fig. 2) forms the largest fresh water ecosystem on the Iranian plateau and one of the first wetlands in the Ramsar Convention (Moghadamnia et al., 2009). Water in the Hamoun lakes is rarely more than 3 m deep, and the size of the lakes varies both seasonally and intra-annually. Maximum expansion takes place in late spring, following snowmelt in the mountains. In years of exceptionally high runoff, the Hamoun lakes overflow their low divides and create one large lake that is approximately 160 km long and 8–25 km wide with ~5700 km² surface area and a volume of 13,000 million m³ (Sharifikia, 2013). An example of the maximum extent of the Hamoun lakes is shown in Fig. 2 (spring 1998) following large floods after snowmelt in the Afghanistan mountains. However, mountain runoff and precipitation vary considerably from year-to-year; thus, the Hamoun lakes completely dried up at least three times in the 20th century (Whitney, 2006). Livelihoods in Sistan are strongly interlinked with and dependent on the wetland products and services, as well as on agricultural activity. Fishing and hunting represent important sources of income for many households and, therefore, the local and regional economy is strongly dependent on weather conditions, precipitation and LULC changes. To counter the effects of drought, the Iranian government offers support, such as flour and other food supplies, medicine, health services and employment in the region, to prevent the forced emigration of people, but continuous and extreme droughts have nevertheless forced some people to leave the Sistan region.

3. Data set

For assessing the objectives of the present work, observations from the Zabol meteorological station along with multiple satellite retrievals (Landsat, TOMS, MODIS, MISR) and model (GLDAS_noah-10) simulations were utilized, covering different periods over the Sistan region and Hamoun basin.

3.1. Meteorological observations

Daily precipitation and visibility data during the period 1985–2005 were obtained from the Zabol meteorological station, located ~10 km from the Hamoun lakes (Fig. 2). Horizontal visibility is systematically measured at 3-h intervals and, then, averaged for monthly and annual means. Similarly, hourly-accumulated rainfall data have been averaged on a daily, monthly and annual basis. In remote desert areas, reduced visibility is associated with dust presence and, therefore, visibility provides an indirect measure of dust load near the surface (Goudie and Middleton, 1992; Engelstaedter et al., 2006). Days with visibility below 2 km are considered dusty days and

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