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18
Natural hazards in Saudi Arabia

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18.1 Introduction

During the last few decades the frequency of the occurrence of natural hazards has increased mainly due to the inhabitation of zones prone to natural hazards. Population pressure has resulted in human settlements in hazardous environments such as on the flanks of volcanoes as in Yogyakarta, Indonesia (Chester *et al*., 2000) or on flood plains as in the Ganges–Brahmaputra delta (Gracheva and Golyeva, 2010) or in low lying or subsiding coastal areas, which can be seen in parts of Netherlands (Leroy, 2013). Natural hazards are threats to life and property only if they occur in populated or inhabited areas. Human intervention has increased the frequency and severity of disasters associated with natural hazards. Four factors which have the potential to change a natural hazard into a disaster include time, space, society, and the type of event (Leroy, 2013). The 13 March 2011 9.0 magnitude earthquake followed by tsunami waves and flooding in Japan, the 2004 Indian Ocean earthquake followed by tsunami waves and flooding in South-East Asia, the 2005 Hurricane Katrina in the USA, the 2005 Kashmir earthquake, and the 2008 Sichuan earthquake in China are just a few examples of the notable natural disasters in the recent past. According to the ISDR disaster statistics approximately 960 000 people were killed during the period 1991–2005 due to natural hazards. Earthquakes, tsunamis, floods, and hurricanes are the most commonly occurring natural hazards that cause wide spread destruction of lives and property on a frequent basis.

The Kingdom of Saudi Arabia is prone to natural hazards. The northwestern region of the Kingdom is prone to earthquakes and volcanic hazards, whereas the central and western regions of the Kingdom are exposed to floods especially during heavy rainfalls. Landslides are a common phenomenon in the inhabited mountainous regions of the southwest. Shifting sand dunes and dust storms are a serious natural hazard being faced by the cities mostly in central and eastern Saudi Arabia. Flash floods, occasional seismic events, and dust storms are the major natural hazards in Saudi Arabia. According to the EM-DAT (http://www.emdat.be/), 14 disasters due to natural hazards occurred in Saudi Arabia between 1980 and 2010 claiming a total of 484 lives and causing over US$1 billion of economic damage.

Arid and semi-arid regions are typically prone to flash floods during rainfall events mainly due to the lack of vegetation and poor infiltration capacity of the surface soils, which results in the generation of enormous volumes of surface runoff. Flash floods have become an issue of concern in the major urban centres around the world. This is mostly because of increasing population pressure, which requires more infrastructural development. This pressure has often resulted in the construction of buildings in topographically low-lying regions, which in turn has obstructed the natural rainwater drainage (Hussein and Zaidi, 2012). The increase of the constructed area has limited the natural land available for infiltration, thus resulting in the generation of more surface runoff, which at times exceeds the normal water bearing capacity of the urban sewer systems, thereby causing floods.

The seismic zones in Saudi Arabia are situated along the Red Sea and the Gulf of Aden in the west and south and the subduction zone associated with the Zagros suture in the north. In general, the damage and losses associated with earthquakes are low over Saudi Arabia, however, the regions along the Red Sea coast are vulnerable to earthquakes. The Dead Sea transform fault along the Gulf of Aqaba is the most seismologically active region of Saudi Arabia. The Gulf region has active sinistral transform faults with associated pull-apart basins and hence is the area where large damaging earthquakes occur.

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Dust and sand storms are other major natural hazards, which are common in the arid and semi-arid regions. They occur when strong wind blows the dust and sand from dry surfaces. The Sahara desert and the dry land around the Arabian Peninsula are the largest sources of airborne dust in the world (Junge, 1979; Morales, 1979; Ganor and Mamane, 1982). Though drought and winds are the major cause of dust storms, they are also caused by poor farming and grazing practices and infrastructure development projects.

18.2 Flood hazard

Flash floods are very common in arid regions and cause wide spread destruction of life and property. The occurrence of flash floods is a complex phenomenon and depends on a number of factors such as regional geology, the morphometric characteristics of the drainage basin, and the flood plain area (Subyani and Al-Dakheel, 2009). Other important factors, which affect the occurrence and severity of flash floods, include the duration and the intensity of rainfall, surface runoff, evaporation, and infiltration rates (Nouh, 2006; Sen, 2008). Flash floods have become one of the significant threats to life and property in many parts of the world mainly due to the increase in population pressure and improper land use planning (Borga *et al*., 2010).

Changes in the global precipitation pattern due to global warming (Groisman *et al*., 2005) have resulted in a change of the planet's hydrological cycle (Huntington, 2006). This global change has resulted in the increase in frequency of flash floods in many parts of the world (Marchi *et al*., 2010), including the arid regions. The magnitude of flash floods in such regions increases further if the soil is saturated due to previous rainfall events.

Saudi Arabia is one of the most arid regions of the world; however this has not prevented the growth of big cities along its coasts, like Jeddah and Dammam, and along the ancient Wadi system, such as Riyadh, Madinah, and Makkah. Though the average annual rainfall in Saudi Arabia is only about 100 mm y^{-1} (Presidency of Meteorology and Environment, 2005), it is not free from hydrological hazards especially in the big cities like Jeddah and Riyadh mainly due to rapid urbanisation which has led to the development of housing in topographically low-lying regions and obstruction of the natural drainage systems. The severe flood in the city of Jeddah in November 2009 as a result of heavy rainfall and the blockage of natural drainage system is one example.

Because of the frequent occurrence of flash floods in the Kingdom of Saudi Arabia, a lot of studies have been focused on flood assessment and flood hazard estimations. Subyani and Al-Dakheel (2009) carried out a study on the hydrological behaviour and flood probability for a few selected basins in the Makkah region in western Saudi Arabia and established the rainfall frequency curves and flood probabilities based on the rainfall records. Al Saud (2010) used a Geographic Information System (GIS) based approach to assess the hazardous impact of flash floods that occurred in Jeddah in November 2009 and emphasised the relationship between urbanisation and the flooding pattern and pointed out the risk of allowing further development in areas at risk of flooding. Dawod *et al*. (2013) established a GIS based process to quantify the peak discharge and runoff volume in Makkah city based on curve number (CN) methodology. Al-Ghamdi *et al*. (2012) investigated the effects of urbanisation on the runoff volume using the CN flood modelling methodology and found a positive correlation between urbanisation, peak discharge, and flood volume.

The Jeddah flood, which occurred as a result of more than 90 mm of rainfall falling within a span of 4 hours on 25 November 2009, was described by the civil defence as the worst in the past 27 years. More than 100 people were reported dead and about 350 people missing. The business damages alone were reported to be about 1 billion Saudi Riyals (Al Saud, 2010). A similar heavy rainfall event of more than 110 mm within a short span flooded the city of Jeddah again on the 26 January 2011 (Fig. 18.1). Though there were only a few deaths, the loss to property was enormous as most of the city's low lying areas were inundated.

Jeddah is situated on a narrow strip along the Red Sea coast with the width of the coastal zone within the city ranging from 5 to 10 km. The coastal plain gives way to the Asir mountain region, which presents an abrupt change in topography showing a very high relief. It was shown that the city of Jeddah serves as the mouth of as many as

Figure 18.1. Flooding in Jeddah, January 2011 (Photo: R. Awad; http://www.moveoneinc.com/blog/moving/jeddah-floods-cause-unknown-delays-to-shipping-times/)

16 watersheds (Al Saud, 2010). The dense drainage networks coupled with thick alluvium deposits in the valley courses were some of the natural causes that attenuated the flooding process. However, the main concern has been the flooding of the city due to anthropogenic causes which resulted from unplanned urbanisation. Construction activities in the topographically low-lying areas have obstructed the natural flow paths of the streams causing inundation, as was the case in November 2009.

The southwestern region of Saudi Arabia generates about 60% of the total wadi flow in the region between the Red Sea coast and the adjacent mountains (Nouh, 2006). Interestingly, this volume of flow is generated in only 10% of the total surface area of the country. The enormous runoff generated during the occasional heavy rainstorms in the region, coupled with the unplanned urban growth are the main causes of the occurrence of flash floods in western and south-western Saudi Arabia. The volumes of the wadi flows in the Arabian platform, east of the Arabian shield, are much lower with the maximum volume of runoff generated in Wadi Al-Dwasir and Wadi Najran.

18.3 Earthquake and volcanic hazards

The Arabian Peninsula is composed of the Arabian Shield (in the west) and the Arabian Platform (in the east) (Rodgers *et al*., 1999). The Proterozoic basement is exposed in the Arabian Shield part, whereas the Platform is covered by Phanerozoic sediments showing a gradual thickening from west to east (Şeber and Mitchell, 1992).

The Arabian Peninsula forms a single tectonic plate (Fig. 18.2) surrounded by active boundaries, where earthquakes occur (Adams and Barazangi, 1984). Following the rifting of the Red Sea Basin some 30 million years ago (Camp and Roobol, 1992), the Red Sea region became a broad zone of active deformation between Africa and Arabia. The Late Cenozoic evolution of Saudi Arabia was mainly controlled by: (i) extensional processes in the Red Sea Basin (Bellahsen *et al*., 2003), (ii) continental collision between Arabia and Eurasia to the east since the Middle Miocene (Ring and Layer, 2003), and (iii) the left lateral strike-slip boundary to the northwest represented by the Dead Sea Transform Fault System (Garfunkel, 1981).

Seismicity in the region (Fig. 18.2(b)) is dominated by the collision of the Arabian plate with the Eurasian plate along the Zagros and Bitlis thrust system (Stocklin, 1968), rifting and sea floor spreading in the Red Sea and Gulf of Aden (Stoeser and Camp, 1985), and strike-slip faults along the Gulf of Aqaba and the Dead Sea Transform Fault System (Garfunkel, 1981; Girdler, 1991). The Dead Sea Transform Fault system connects the active spreading centres in the Red Sea to the convergent zone between the Arabian and Eurasian plates in southern Turkey, The seismicity in its vicinity is characterised by swarm and mainshock–aftershock types of earthquake activities (Al Amri and Rodgers, 2013).

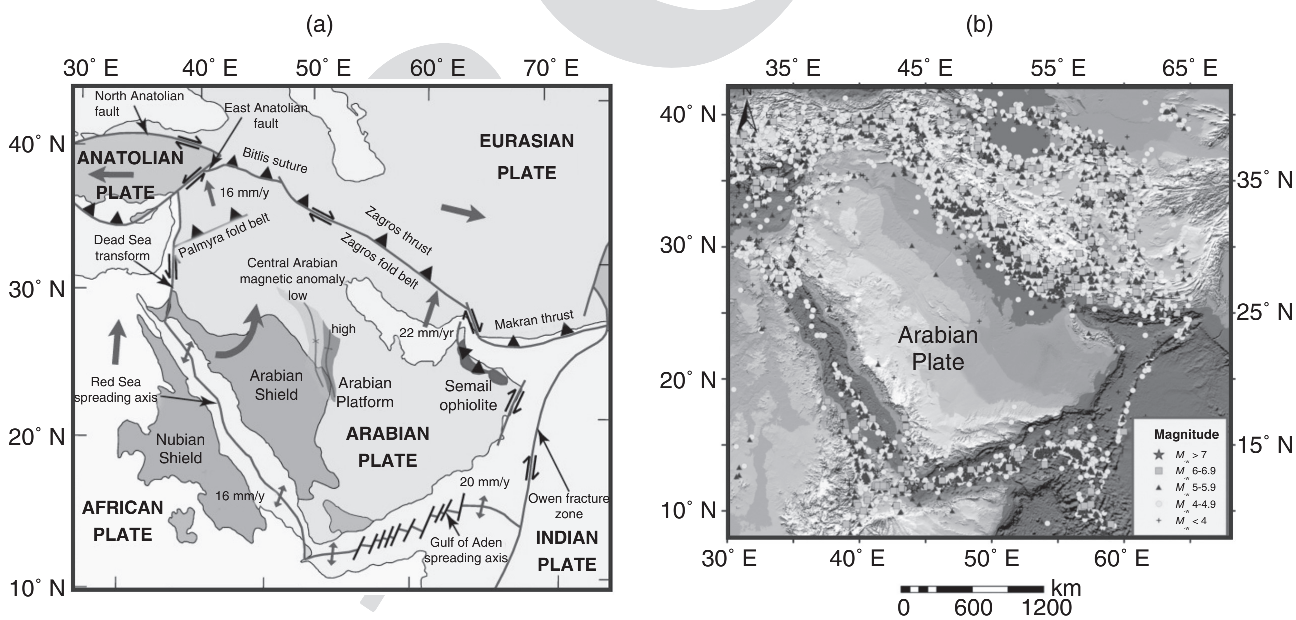

Figure 18.2. Tectonic setting (a) and seismicity (b) of the Arabian Plate (after Stern and Johnson, 2010; Deif and El-Hussein, 2012). Bold arrows show the plate movement.

The main zone of active tectonics in the Red Sea region lies along a belt that extends from the central Red Sea to the south of Afar and then eastward through the Gulf of Aden. There is little seismic activity in the northern Red Sea (Al Amri, 1995). The main threat to Saudi Arabia in terms of seismic hazards is from the significant number of earthquakes occurring in the Gulf of Aqaba including the large earthquakes and swarms in 1983, 1990, 1993, 1995, and 2004 (Al Amri, 1995; Klinger *et al*., 1999; Ambraseys *et al*., 2005; Al Damegh *et al*., 2009).

The lack of seismicity in the interior of the Arabian Peninsula suggests that internal deformation of the Arabian plate is insignificant. However, the major cities in the Gulf region are situated along the eastern margin of the Arabian plate and are within 300 km of the collision zone between the Arabian and Eurasian plates. Strong earthquakes of magnitude greater than 5 are common along the Zagros thrust belt (a collision zone between the Arabian and Eurasian plate). Though the epicentres of these events are more than 200 km from the cities situated along the Arabian coast, seismic waves travelling through the sedimentary structures of the Arabian platform are capable of long duration ground motions (between 3 and 10 seconds) and are a potential threat to the engineering structures in the region (Al Amri *et al*., 2008). Al Amri and Rodgers (2013) delineated the seismic zones in the Arabian Platform based on seismological and geological parameters. The seismological parameters included the spatio-temporal distribution of the seismic events indicating the seismogenic provinces and seismoactive faults and the occurrence of large earthquakes. The geological parameters included the location of the major faults, lineaments, joints, and rift systems that are associated with seismic activities.

The southwestern Arabian Shield and the southern Red Sea region gained importance in terms of seismic hazard assessment because of the extensive urbanisation in the region in the past years including strategic development projects and new urban communities (Al Amri and Rodgers, 2013). Historical and instrumental records of the earthquakes in the region show that most of the seismic events occur along the axial trough of the Red Sea (Al Amri, 1994). However, four strong earthquakes (*M*6.2 in 1941, *M*5.7 in 1955, *M*4.7 in 1962, and *M*6 in 1982) occurred away from this axial trough (Langer *et al*., 1987). Based on seismicity, the region is divided into four seismic source zones: the Sanaa-Dhamar, the southern Red Sea, northern Yemen, and the middle of the Red Sea zone (Al Amri and Rodgers, 2013).

The tectonic evolution of the Arabian plate resulted in large volumes of Cenozoic volcanism, mainly along the western margin of the Arabian plate (Segev, 2005; Trifonov *et al*., 2011; Chang and Van der Lee, 2011; Moufti *et al*., 2012). The volcanic fields are situated in the rifted neo-Proterozoic crust and include parts of Syria, Lebanon, Jordan, Saudi Arabia, and Yemen (Fig. 18.3) forming one of the world's largest intraplate volcanic provinces (Coleman *et al*., 1983). These lava flows are mostly dominated by alkali olivine basalts and hawaiite (Moufti *et al*, 2013).

The presence of recent volcanism in the Arabian shield makes it different from the other shield areas of the world (Rodgers *et al*., 1999). The opening of the Red Sea and the corresponding upwelling of the asthenosphere beneath western Saudi Arabia is likely to be the most probable cause for the volcanic activity (Camp and Roobol, 1992). The volcanic sequences are represented by a thick sequence of basaltic lava flows including pyroclastic cones, shield volcanoes, and hydro magmatic craters (Al Kwatli *et al*., 2012) ranging in age from 30 Ma to recent (Shaw *et al*., 2003; Ibrahim *et al*., 2003; Weinsten *et al*., 2006).

Based on ages and the structural pattern of the vents, the Arabian Shield volcanism is divided into two periods (Coleman *et al*., 1983; Camp and Roobol, 1992). The first period of volcanism (30–15 Ma) was associated with the doming and rifting of the Proterozoic basement of the present Arabian Nubian Shield along the north-northwest trending rift system leading eventually to the opening of the Red Sea basin. The second period of volcanism ($<$ 12 Ma) is characterised by north–south trending vent system associated with the onset of a new north–south trending 900 km long crustal rift system passing through the 600 km long Makkah-Madinah volcanic line (Camp and Roobol, 1992). Individual volcanic fields can be very large, such as Harrat Ash Shams and Harrat Rahat. Harrat Al Madinah volcanic province (a part of Harrat Rahat) is an active volcanic field characterised by two historical eruptions, one in 641 AD and another in 1256 AD (Moufti *et al*., 2013).

Northwestern Saudi Arabia experienced notable earthquakes during April–June 2009. These earthquakes took place beneath Harrat Lunayyir (Palister *et al*., 2010). The peak seismic activity (19 earthquakes of magnitude 4 or greater) was recorded on 19 May 2009 by the Saudi Geological Survey's (SGS) telemeteric network of broadband seismometers. The maximum magnitude recorded was 5.4, and this earthquake caused minor structural damage in the town of Al-Eis about 40 km from the city of Madinah (Pallister *et al*., 2010). As a result of this earthquake, a northwest trending 8-km-long surface rupture propagated across the northern part of the volcanic field (Fig. 18.4). The shallow crustal earthquakes were grouped into two depth clusters: 5–10 km and 13–20 km suggesting a dyke intrusion could be responsible for this earthquake swarm (Mukhopadhyay *et al*., 2013).

The origin of the 2009 earthquake swarm is still unknown. The key question is whether the earthquakes were of a tectonic origin or were triggered by a magma movement. Crustal expansion was responsible for

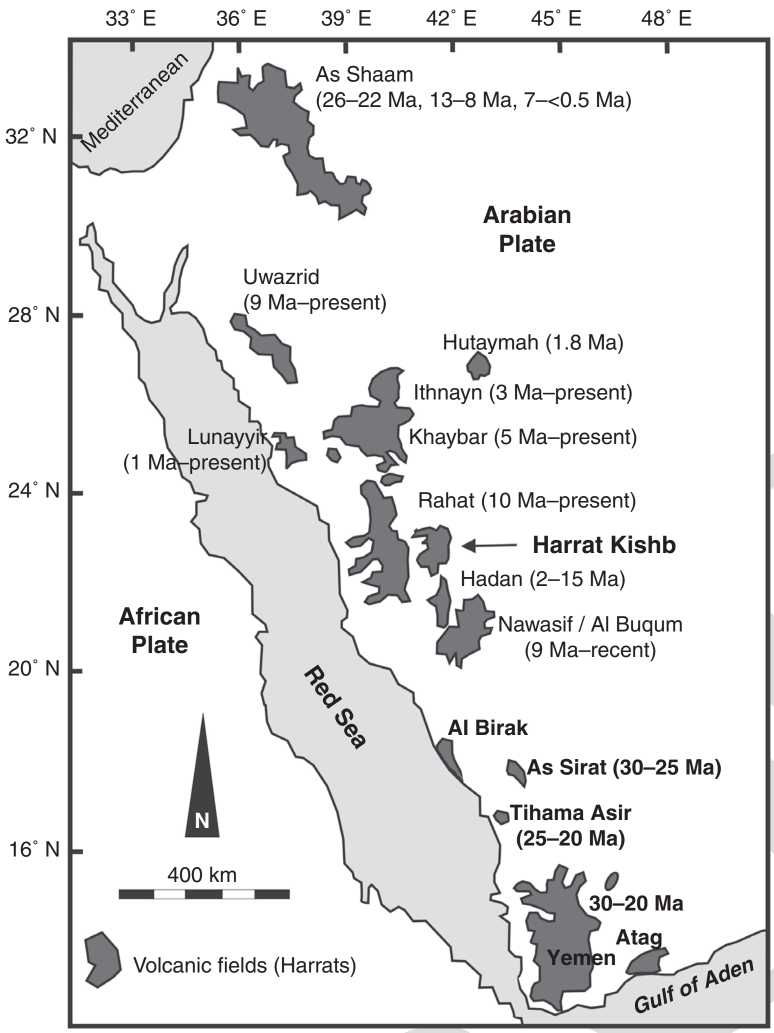

Figure 18.3. Cenozoic volcanic fields of the Arabian Peninsula (after Abdel Wahab *et al*. (2013)).

Cenozoic volcanism in central western and northwestern Saudi Arabia. Historically the area has witnessed volcanic eruptions, with the last recorded eruption taking place about 1400 years ago (Grainger, 2007). If a magma movement triggered the 2009 earthquakes in the region, then some magmatic processes are still active in the region.

18.4 Dust storms

Shifting sand dunes and dust storms are a serious natural hazard being faced by cities mostly in central and eastern Saudi Arabia. The phenomenon has become more common in the recent years due to the expansion of cities, road, and infrastructure development. The Middle East region is the world's second (after Africa) most dust-affected area (Kutiel and Furman, 2003). The quantity of dust present in the air at any given time is directly related to the wind velocity. Therefore, understanding the atmospheric air circulation in the region provides a clue to the probable times of dust storms. Dust storms affect daily life for from a few hours to a few days depending on the storm severity (Maghrabi *et al*., 2011). The most important issue associated with dust storms is the reduction of visibility that increases the incidence of traffic accidents and may increase the occurrence of vertigo in aircraft pilots (Dayan *et al*., 1991; Kutiel and Furman, 2003). The suspended air particles have a significant impact on human health (Bennett *et al*. 2006; Bennion *et al*., 2007) especially for patients suffering from lung disease. Other environmental impacts may include damage to telecommunication and mechanical systems, reduction in soil fertility, and damage to crops.

The frequency of sandstorms increases between March and May. The dust originates mainly from the arid areas across the Arabian Peninsula and is transported by the southwestern winds towards the east (Ackerman and Cox, 1989). Since dust storms in Saudi Arabia are a

Figure 18.4. Rupture created by the Al-Eis earthquake in May 2009. (Photo: Omar Lafouza, KACST, Riyadh, Saudi Arabia.)

common phenomenon, their impact on the environment has been intensively studied (e.g., Smirnov *et al*., 2002; Al Harbi and Moeid, 2005; Badarinath *et al*., 2010; Maghrabi *et al*., 2011).

The very severe dust storm of 10 March 2009 in the Riyadh region was visible from space (Fig. 18.5). The dust storm disrupted air traffic in Saudi Arabia for several hours. Magrabhi *et al*. (2011) carried out a detailed analysis of this storm event in terms of meteorological parameters: the aerosol optical depth, the ångström exponent, the infrared sky temperature, and the emissivity. Their findings showed that the effects of the storm were associated with an increase in both atmospheric pressure and humidity and a reduction in temperature and visibility, two days after the storm as compared to the conditions before it. The infrared sky temperatures and the emissivity remained at higher levels after the storm as compared to the pre-storm conditions.

18.5 Disaster risk reduction (DRR) in the Kingdom of Saudi Arabia

DRR strategies involving governmental and non-governmental/private organisations, communities, and individuals have resulted in reducing the risks associated with human and economic losses, thus reducing the overall impacts of natural hazards (Innocenti and Albrito, 2011). There are a number of government agencies in Saudi Arabia continuously engaged in research on natural hazards, prevention, and mitigation, and the development of early warning systems in case of a natural calamity.

The Directorate General of Civil Defence is the premier national agency responsible for prevention and mitigation of disasters due to natural hazards in the country. The Directorate issues early warnings in the case of dust storms, heavy rainfall, and flash floods, and adopts and hosts a number of initiatives to protect lives and property in the kingdom from all types of natural hazards. Several awareness programmes are organised by the directorate to try to educate the general public and especially the children on how to respond before and after a natural disaster.

The SGS is another government agency mainly engaged in research and gathering primary information on natural events such as earthquakes and volcanic activity in the kingdom. Due to the increase in population and the expansion of the urban areas, more and more areas are being exposed to the risks of natural hazards. The SGS is continuously working towards development of methodologies and strategies to reduce or mitigate the effects of the natural hazards. The National Centre for Earthquakes and Volcanoes at the SGS is engaged in close monitoring of earthquake and volcanic activity within the kingdom and cooperation with the international Earthquake Data Centre for exchange of data. The centre is also involved in raising public awareness related to earthquake hazards in the kingdom and the risks related flash floods within the major cities. The SGS Research Chair on Natural Hazards housed within the Department of Geology and Geophysics at King Saud

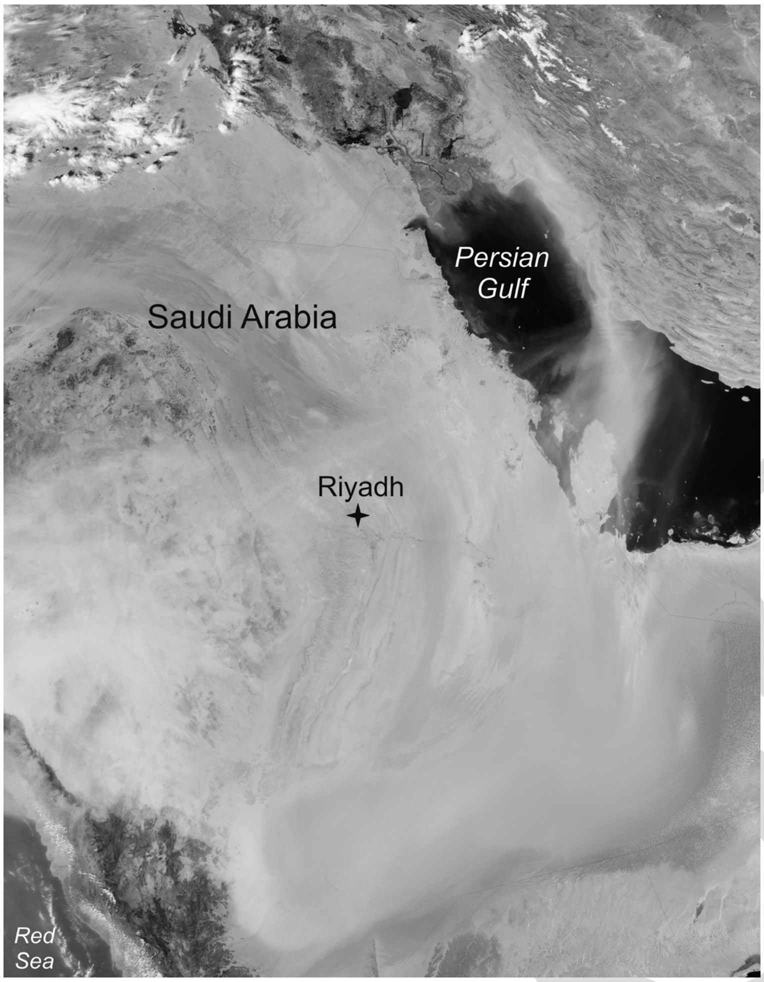

Figure 18.5. A satellite image of the dust plumes (translucent blurs) over the Arabian Peninsula on 11 March 2009. (Photo: Jeff Schmaltz, MODIS Rapid Response Team, Goddard Space Flight Center, NASA.) For colour version, see Plates section.

University is involved in innovative research and education in the field of natural hazards and disaster risk reduction and mitigation in Saudi Arabia, addressing the essential issues and problems related to the prediction of natural hazards, early warning systems, and hazards risk assessment.

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