# Managing the Hazards of Drought and Shifting Sands in Dry Lands: The Case Study of Kuwait

**Chapter** · January 2013

DOI: 10.1007/978-94-007-5332-7_41



**3 authors**, including:

Fikry Khalaf
Kuwait University



Samira AS Omar
Kuwait Institute for Scientific Research

# Chapter 39
# Land-Use Planning for Controlling Land Degradation in Kuwait

**Fikry I. Khalaf, Jasem Al-Awadhi, and Raafat F. Misak**

**Abstract** Several land degradation indicators have been recognized in Kuwait; these are soil loss by wind and/or water; soil crusting, sealing, and compaction; soil contamination by oil; soil salinization; deterioration of vegetation cover and its biodiversity; and hydrological degradation. Aeolian processes, as manifested by soil deflation, drifting sand, and migrating dunes, may be considered as one of the primary causes of soil degradation in Kuwait. The present status of land degradation as reflected by the severity of degradation of vegetation cover, soil erosion/deflation, and hydrological drought has been assessed based on visual comparison between data recorded in the early 1980s and recent field surveys (early 2010). It has been concluded that the northwestern and southern parts of Kuwait are severely degraded. Anthropogenic activities (off-road vehicle traffic, excessive grazing, camping, and quarrying) as well as military operations (Gulf Wars and present defense structures) are the main causes of land degradation in Kuwait. However, aeolian processes, nature of surface sediments (soil type), and climatic conditions play a significant role. It was also recognized that the sandy soils (Torripsamments) that cover most of the southern part of Kuwait are the most vulnerable to aeolian processes, particularly soil loss by deflation. Hence, mitigation measures for the maintenance of Kuwait desert ecosystem are recommended.

F.I. Khalaf (✉) • J. Al-Awadhi
Earth and Environmental Science Department, Faculty of Science,
Kuwait University, Kuwait, Kuwait
e-mail: fikry_khalaf@hotmail.com

R.F. Misak
Environment and Urban Development Division, Coastal and Air Pollution Department,
Kuwait Institute for Scientific Research (KISR), P. O. Box 2488513109 Safat, Kuwait
e-mail: rmisak@kisr.edu.kw

S.A. Shahid et al. (eds.), *Developments in Soil Classification, Land Use Planning and Policy Implications: Innovative Thinking of Soil Inventory for Land Use Planning and Management of Land Resources*, DOI 10.1007/978-94-007-5332-7_39,

**Keywords** Anthropogenic activities • Kuwait • Land degradation • Land-use planning • Military operations

## 39.1 Introduction

Land degradation is believed to be one of the most severe and widespread global environmental problems (Dregne et al. 1991; Dregne 1992; Oldeman et al. 1992; UNEP 1992; UNCED 1992; Maingnet 1994; Lal and Stewart 1994; Johnson and Lewis 1995; Middleton and Thomas 1997; Lal et al. 1997; Reynolds and Smith 2002; Al-Awadhi et al. 2005a). The term land degradation, as defined by UNEP (1992), is a process, which lowers the current and/or the potential capability of land to produce goods or services (quantitatively and/or qualitatively).

Dry lands are particularly susceptible to degradation, and although they cover about 41% of Earth's land surface (Safriel and Adeel 2005), estimates of the extent and severity of degradation vary greatly (Lepers et al. 2005). There are estimates that 70% of the world's dry lands are affected and that at least one third of the present deserts are man-made (UNCED 1993; Le Houérou 1996; Warren et al. 1996; Ravi et al. 2010). According to Kassas (1995) and Agnew and Warren (1996), it is particularly the semiarid regions of the world that are most susceptible. At the same time, these regions, both rich and poor, are experiencing some of the highest population growth rates worldwide (Warren et al. 1996).

Land degradation stems from an imbalance between the fragile environment and human economic activity, among many other factors. In other words, land degradation in ecologically vulnerable region is the outcome of irrational unsustainable land use and lack of proper resource management. Rational and effective measures for controlling and rehabilitation of degraded lands should be based on a thorough understanding of the causes and pattern of land degradation.

In recent decades, Kuwait has suffered severe land degradation, as noted by several authors (e.g., Khalaf 1989; Omar 1991; Zaman 1997; Brown 2003; Brown and Porembski 1997, 1998, 2000; Howle 1998; Misak et al. 1999; Shahid et al. 1998, 1999, 2003; Al-Dousari et al. 2000; Al-Awadhi et al. 2001; Omar et al. 2001, 2005). The main causes of this problem can be attributed principally to overgrazing, but also to recreational activities such as off-road driving and camping, as well as industrial practices, particularly quarrying (Khalaf 1989). In addition, serious damage was inflicted on the natural environment during the recent Iraqi occupation and the hostilities associated with the liberation of the country during the Gulf War (Shahid et al. 1999; Al-Awadhi 2001). The study of Misak et al. (1999) indicated that at least 76% of the desert ecosystem of Kuwait suffers different degrees of land degradation, 44% moderately, and 32% being severely degraded.

Although globally, the world main concern of land degradation is due to a decrease in land capabilities and productivity, the main concern in Kuwait may be attributed to the associated deterioration in the desert ecosystem particularly environmental quality and biodiversity. Land capability for grazing activities has high cultural importance; however, it is economically insignificant.

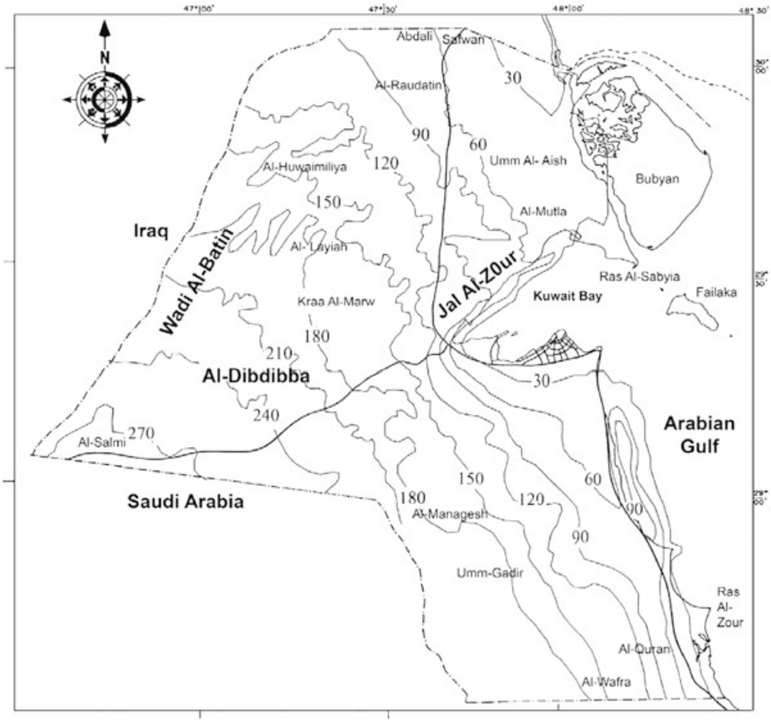


**Fig. 39.1** Location map of Kuwait

This chapter provides a review of published work on land degradation of Kuwait. Also, the present status of land degradation as reflected by the severity of degradation of vegetation cover, soil erosion/deflation, and hydrological drought are assessed based on visual comparison between records and observation by the authors in early 1980s of the last century and their recent field surveys during the period of January–March 2010. An assessment of the vulnerability of the various soil types in the northwestern and southern areas of Kuwait to aeolian processes, particularly soil loss by deflation, is discussed. Causes and consequences of land degradation are also discussed and mitigation measures to alleviate the severity of land degradation in Kuwait are recommended.

## *39.1.1 Natural Environment of Kuwait*

The State of Kuwait is situated at the northwestern corner of the Arabian Gulf, and it covers an area of 17,818 km$^2$ (Fig. 39.1). Summer is very hot, especially in July and August, with mean temperatures of 37.4°C and maximum mean temperatures of 45°C. On a monthly basis, potential evapotranspiration far exceeds precipitation throughout the year. Rainfall is scarce and irregular; it varies from 28 mm (1963–1964) to 260 mm (1975–1976), and the total average of rainfall is approximately 115 mm year$^{-1}$, with an evaporation rate of 16.6 mm day$^{-1}$.

Wind direction in Kuwait is fairly consistent; about 75% of the winds blow from the west, northwest, and north. The average monthly wind speed ranges from 8.7 knots (in January and December) to 11.2 knots (in June and July). Sand and dust storms are frequent during the summer period.

The surface of Kuwait is carved from the Mio-Pleistocene calcretic formation during early Holocene pluvial periods. The carved depressions and water courses are filled by the fluvial and alluvial sediments. By the advent of aridity, aeolian processes started to act on these fluvial sediments as the present-day aeolian landforms were developed. These landforms can be grouped into erosional and depositional landforms. Erosional landforms are represented by (a) calcretic and gypcretic rock exposures, which occur as flat terrain and small humps and some are yardangs; (b) desert pavement represented by pebbly lag, granule lag, and mixed lag; and (c) granule ripples. Depositional landforms include (a) sand dunes, (b) nabkhas and sand drifts, (c) sand sheets, and (d) anthropogenic-related sand accumulations. Sabkhas and tidal flats are the most dominant landforms in the coastal zone.

The open rangeland is flat to slightly undulating desert plain sloping gently toward the northeast from about 280 m above sea level near Wadi Al-Batin in the extreme southwestern corner of the country toward the Arabian Gulf coast in the east. It is broken by occasional ridges, low hills, wadies (drainage lines), depressions, and sand dunes. Two prominent ridges dissect the northwestern part of the rangeland, namely, Al-Layiah and Kraa Al Marw, which are made up of gravelly gypcretic calcrete. Less prominent discontinuous smaller ridges are parallel to these ridges. They are separated by relatively flat desert plains covered by desert pavement (pebbly lag). Isolated calcretic hills are frequent in the southwestern area. Permanent or even intermittent streams are lacking in Kuwait. Dense internal drainage systems occur in the northern area especially in the Rawdatain and Umm Al-Aish areas where they converge into a fairly large depression. Small depressions (playas) are encountered in the north, central, and western parts. Wadi Al-Batin, the largest wadi in the country, marks the northwestern border with Iraq. It reaches a width of 8–11 km and a depth of about 50 m below the level of the adjacent plateau.

Due to the harshness of the climate, pedogenesis is minimal, leaving the sandy or gravelly parent material little altered by the soil-forming processes. In most southern areas, Torripsamments are prevalent, whereas Petrogypsids, Calcigypsids, and Haplocalcids predominate in many northern and western parts of the country (Kuwait Institute for Scientific Research 1999; Omar et al. 2000) (Fig. 39.2).

According to Halwagy and Halwagy (1974) and Halwagy et al. (1982), three distinct vegetation communities are present, namely, (a) a dwarf shrub community of Rhanterium epapposum dominated the southern half of the country; (b) Cyperus conglomeratus which replaces R. epapposum as the key perennial species, probably as a result of overgrazing; and (c) the chenopod Haloxylon salicornicum community that is prevalent in the northern Kuwait.

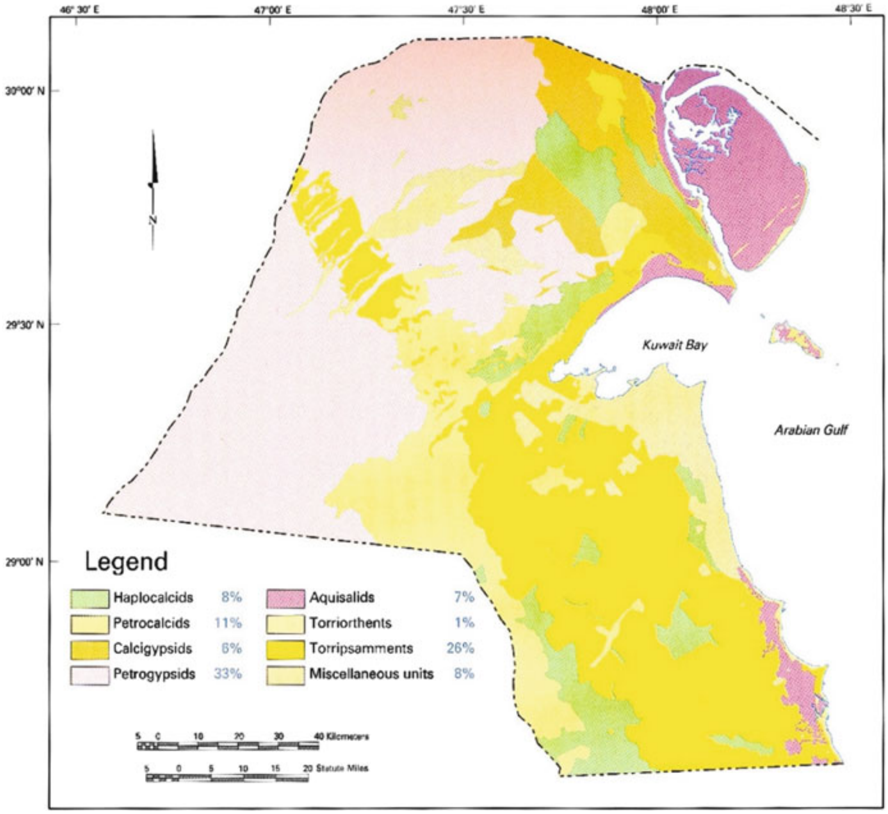


**Fig. 39.2** Generalized great group soil map of Kuwait

### *39.1.2 Land Use*

Nineteen land-use types are recognized within Kuwait territory (Fig. 39.3). These can be grouped into six main land-use types, namely, open rangeland, oil fields, protected areas, agricultural areas, military areas, and urban areas. Open rangeland, which is the subject of the present study, constitutes about 75% of Kuwait's terrestrial area.

## 39.2 Manifestation of Land Degradation

Land degradation processes are prevailing in the majority of the terrestrial environment of Kuwait in general and in the open rangeland in particular. This is mainly manifested by the destruction of the vegetation cover and soil erosion by aeolian

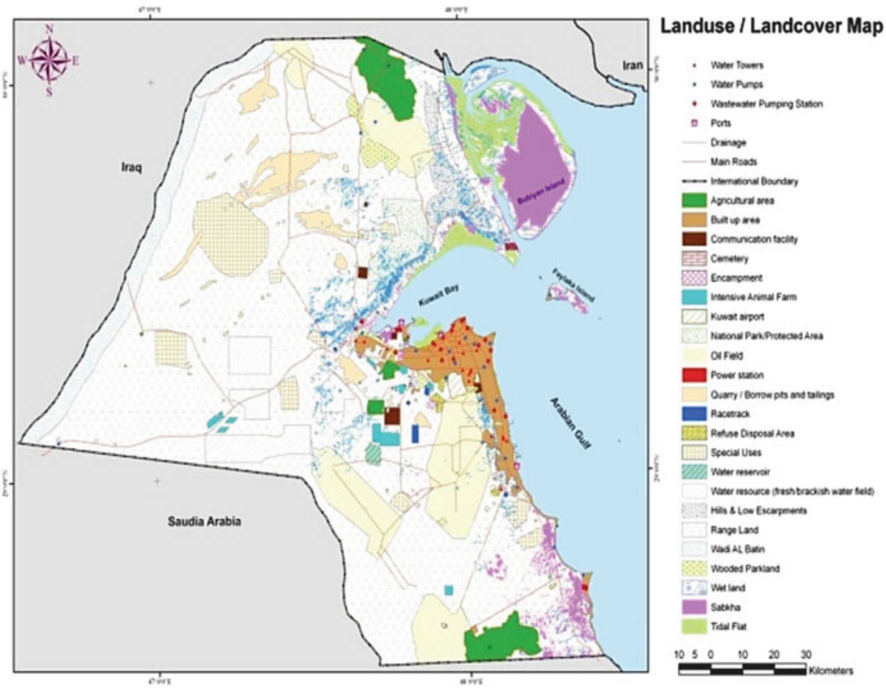


**Fig. 39.3** Current land-use map of Kuwait

and fluvial processes. The following is a description of the observed changes in the vegetation cover, surface sediments/soil, and the pattern of surface hydrology.

### *39.2.1 Deterioration of the Vegetation Cover*

A comparison between the densities of the vegetation cover (mainly perennial desert shrubs) recorded during the early 1980s to that observed in February 2010, revealed a state of severe degradation. The first author of this chapter prepared a sedimento-morphic map for the State of Kuwait during early 1980s (Khalaf et al. 1984). This map indicates that most of the western and southern parts of Kuwait were covered by rugged vegetated sand sheets (RVSS), which were developed by the coalescence of nabkhas (Fig. 39.4a). These areas were characterized by dense to moderate vegetation cover.

At present, living desert shrubs (Haloxylon salicornicum) were rarely observed within these areas. The RVSS have been replaced by thin sand sheets, mostly covered by granule lag. The densely populated shrubs, that at one time use to stabilize the RVSS, have been almost totally weathered or died, with remnants of these shrubs represented by dead or dying stems and roots still

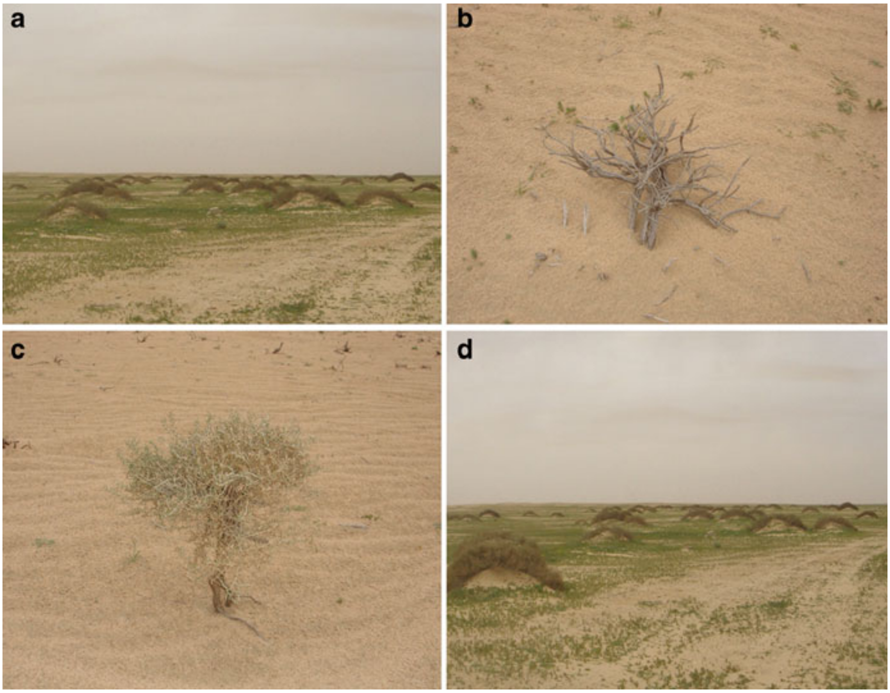


**Fig. 39.4** Rugged vegetated sand sheets in 1982 (**a**), eroded rugged vegetated sand sheets (2010), note remnants of eroded nabkhas with residues of dried up Haloxylon roots and stems (**b**), granule ripples (2010) (**c**), well-developed nabkhas at Ras Al Subbiya (2010) (**d**)

marking the original occurrences of the once existed nabkhas (Fig. 39.4b). However, in most areas the only existing nabkhas have totally been disappeared and the bedrock is exposed.

The depositional nabkhas which flourished during early 1980s have been extensively eroded. The present erosional phase of nabkhas started after the destruction of the vegetation cover. Where sand mounds that formed the nabkhas sediments have been deflated, and these have been replaced by granule residuals mostly in the form of granule ripples (Fig. 39.4c).

Some of the more intact Haloxylon stands were encountered within the Ras Al Subbiya area. Also, the vegetation cover in the demilitarized zone along the northern and northwestern border area between Kuwait and Iraq is relatively dense, where grazing and recreational pressures are considerably forbidden. In these areas well-developed H. salicornicum nabkhas are flourishing (Fig. 39.4d). Brown and Porembski (1997) broadly recognized four distinct stages of desertification within the Haloxylon community. Stages 1 through 3 involve a gradual decrease of Haloxylon cover and loss of sand, while severe degradation occurred in the fourth stage. The latter was characterized by the near total loss of Haloxylon cover and severe reduction in vegetation productivity. The present observation contradicts the conclusion of Wang et al. (2006), who stated that nabkha formation is a good indicator of wind erosion and land degradation.

### *39.2.2 Soil Erosion*

Two processes are responsible for soil erosion in Kuwait, namely, aeolian processes (wind erosion), which is the most predominant, and fluvial processes (water erosion). Active aeolian processes in Kuwait are attributed to a combination of the nature and fragility of the desert ecosystem, prevalent climatic conditions, and the uncontrolled human activities. In particular, the following conditions are accelerating soil erosion: (a) the location of Kuwait downwind of the high deflation area of the Mesopotamian flood plain (which forms a source for regional sand supply), (b) the higher proneness of both unconsolidated and consolidated deposits to wind and water erosion (this ultimately forms as the source for local sand supply), and (c) the near absence of effective biological soil stabilization (that is usually provided by deep-rooted shrubs and trees) (Khalaf and Al-Hashash 1983; Khalaf and Al-Ajmi 1993; Al-Awadhi and Misak 2000).

The terrestrial environment of Kuwait especially its central part (about 60% of total area) is an open theater for extremely active aeolian processes, where significant active sand bodies (dunes and sand sheets) dominate. Application of a sand transport model developed by Al-Awadhi and Al-Awadhi (2009) showed that the calculated average monthly rate of sand transport during summer is about 5,900 kg $m^{-1}$ toward the southeast. They recognized that the highest sand transport rate occurs within the Al Huwaimiliya sand dune corridor (Fig. 39.5).

Wind erosion (soil drifting) is very common in the areas of fragile sandy soils which cover more than 50% of the terrestrial environment of Kuwait. Recent field measurements indicate that the 2007/2008 dry season (less than 30 mm rainfall) resulted in severe soil losses through wind erosion. Over an extended period of time, winds removed 10–15 cm thick of top soils (around 1,000 $m^3$ $ha^{-1}$) (Fig. 39.4c).

In the early 1980s, the desert sediment approached equilibrium, that is, areas of deposition were nearly equal to erosional areas (Khalaf and Al-Ajmi 1993). At present, in 2010, the distribution pattern of the depositional and erosional landforms has been drastically changed. The sediment (deposition) budget has deviated from a balanced budget to a budget dominated by erosion. With the exception of sand dunes, most of the aeolian depositional landforms have been altered to erosional landforms; for example, the previously identified RVSS has been altered to granule lag or desert pavement. Relatively thick sand sheets that used to dominate the southern part of the country have been transformed to thin smooth sand sheets covered with a thin veneer of granule lag. In the early 1980s, these thick sand sheets consisted of a well-developed sandy soil, particularly in areas where the dense community of perennial shrub Cyperus conglomeratus acted as a stabilizing agent and enhanced the depositional aeolian processes.

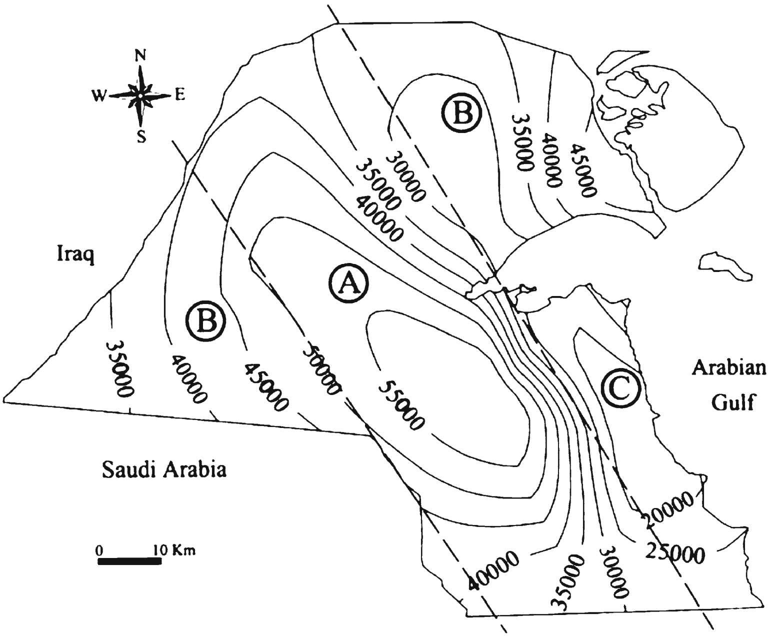


**Fig. 39.5** Spatial variation of sand transport rate (kg m$^{-1}$) in Kuwait. Letters indicate zones of sand transport rate: (A) severe, (B) moderate, and (C) slight

The country is crossed from NW to SE by a deflational corridor (Al Huwaimiliya belt). It is bounded by elevated grounds and dissected transversely by elevated calcretic and gypcretic gravelly ridges. The low-lying areas between these ridges are desert plain mostly covered by pebbly lag. In the early 1980s, abundant small-size barchan dunes (about 3 m high) were scattered within these low-lying areas. Field observation in February 2010 revealed the occurrence of two types of dunes, namely, (a) the Al Huwaimiliya small barchan dunes that were recorded in 1984 and (b) large barchan dunes (about 10–12 m in height). The latter type was not observed in 1984 and has most probably developed since the end of the Gulf War in 1990. There exists a need to investigate the causes and mechanism of the development of these dunes.

Although rainfall in Kuwait is scarce, in some rainy seasons, intensive showers are experienced for short duration (usually in excess of 20 mm day$^{-1}$). This may result in the occurrence of erosive surface runoff. Misak et al. (2001) identified three degrees of water erosion in Kuwait based on the depth of gullies and rills, namely, strong, moderate, and slight. Strong water erosion creates gullies ranging in depth from 50 to 150 cm and rills of 20 to 50 m interspacing. Accelerated water runoff in Kuwait usually prevails in areas where natural drainages are degraded by grazing and other human activities.

### *39.2.3 Vulnerability of Soil Classes to Degradation*

In Kuwait, eight soil types were mapped by Kuwait Institute for Scientific Research (1999) at great group level using the USDA soil taxonomy. These are Haplocalcids (8%), Petrocalcids (11%), Haplogypsids (0.5%), Calcigypsids (6%), Petrogypsids (33%), Aquisalids (7%), Torriorthents (1%), and Torripsamments (27%), in addition to a miscellaneous unit (7%). These soil types exhibit different vulnerability to degradation and drought conditions.

It is very difficult to categorize soil types based on their vulnerability to degradation; however, three categories are tentatively identified. These are high, moderate, and low vulnerable. Torriorthents (1%) and Torripsamments (27%) have high vulnerability to degradation, while Aquisalids (7%) have medium vulnerability. The remaining have low vulnerability.

### *39.2.4 Abundance of Bedrock Exposures*

A comparison between the present occurrence of exposed calcretic and gypcretic bedrock (October 2010) with that of the early 1980s revealed a significant increase in the locations of the exposed bedrock, particularly in the northwestern and southern areas. Such relative abundance of the exposed bedrocks may be attributed to the severe deflation/erosion of the loose surface sediments. The increase in the bedrock exposures indicates the erosion of the loss sediments/soil that previously covered the bedrock of these areas. Accurate assessment of the increase of bedrock exposures requires a detailed study for the temporal change detection using sequential satellite images.

The exposed bedrock occurs as almost flat to low humps of calcrete and gypcretic calcrete in the western and southern parts of Kuwait. Most of these humps are oriented parallel to the prevailing wind direction, that is, NW-SE, with some having a yardang morphology.

### *39.2.5 Enhancement of Sand Encroachment*

Most of the developed areas and defense facilities that are located within the main passage of the wind corridor (classified as high to very high encroachment zones) are subject to extensive and intensive sand encroachment. Al-Awadhi and Misak (2000) identified 13 mobile sand bodies in Kuwait (Fig. 39.6). These facilities include installations of oil fields (pipelines, well heads, etc.), installations of groundwater fields, air bases, military encampments, animal production farms, roads and highways, electrical transmission stations, and water storage facilities. The total sand removed from such installations, including motorways, oil wells and gathering centers, air bases, and electric power stations, is estimated at about $4.39 \times 10^{6}$ $m^{3}$. The estimated cost for removal of the wind deposited material is a staggering figure of nearly Kuwaiti Dinar (KD) 1,680,000 $year^{-1}$ (Al-Awadhi and Misak 2000). Some


**Fig. 39.6** Mobile sand bodies in Kuwait

development sectors spend millions of KD for sand clearance, for example, "KD 6.2 millions" for KOC in the period 2003–2008. Currently, Kuwait lacks a sustainable action plan (SAP) for managing the hazards of sand encroachment.

The 2007/2008 drought resulted in massive wind erosion, severe sand encroachment, and extensive soil loss even in protected areas. Also, occurrence of severe dust storms (for days and sometimes week) was recorded. During this period road accidents significantly increased on the main highways.

The recent field survey (January 2010) in the central part of the country (Al Qurain-Wafra) indicates that northern farms of Wafra agricultural area, Wafra-Ras Azour oil flow lines, and a water storage facility are being severely encroached by shifting sands. These facilities are located at the extreme downwind side of the natural wind corridor (Al Huwaimiliya-Wafra). The source of shifting sands is the huge undulated sandy plain stretching from the upwind side of the attacked facilities. The thickness of accumulated sand ranges between 50 and 120 cm.

### *39.2.6 Disruption of Surface Hydrological Conditions*

Recent field observations (2009/2010) indicate that a number of land uses have negative impact on recharge conditions of vital shallow groundwater reservoirs. The natural flow of runoff water of several catchment areas is disrupted by bund walls, roads, and highways. Blocking of runoff water during floods is the most common mechanism of hydrological disruption in several parts in Kuwait, specially its northern and western fringes.

In the 2009/2010 wet season, huge amounts of runoff water were blocked against bund walls (berms) which act as dykes (1.5–2 m in height, 2–3 m in width, and tens of km in length). A good example is the disruption of the drainage system within Rawdatain-Umm El Eish catchment, where at least 40% of runoff water does not reach to Ar-Rawdatain-Umm El Eish depressions (discharging areas). Also, a bund wall running for about 75 km and at about 2 km to the south of the Kuwait northern border with Iraq currently blocks a network of drainage systems and disrupts the runoff drain to the nearby depressions in southern Iraq. Since most of the drainage systems in Kuwait (particularly at the north) are running in an east to west direction, most of the roads and highways that are trending in a north-south direction (Al Mutla-Safwan and Ras Al Subbiya-Abdali highways) are also blocking normal surface runoff.

Bund walls and roads crossing drainage systems act as dams and accumulate surface runoff during rainy seasons at their upstream side. Field observation after the last rainfall (in November 2009–January 2010) revealed the occurrence of several extensive water ponds within shallow depressions at the upstream side of bund walls and highways at many localities in the northern and southern parts of the country. Some of these ponds extend for about 1 $km^2$ and the quantity of accumulated runoff water was estimated at 200,000 $m^3$. Assuming that such ponds deposit about 5 cm thick of outwashed material, this may result in the deposition of about 50,000 $m^3$ of fine-grained sediments. The deposited mud dries up and desiccated cracks developed.

Blocking of runoff at the upstream of the drainage systems by the bund walls and roads and highways is responsible for hydrological drought at their downstream. This may result in significant drop of soil moisture and consequently deflation of wadi fill at downstream of the bund wall is accelerated. In addition, off-road traffic and grazing along the dry cracked mud flats result in their fragmentation and disaggregation and present a local source of dust storms during active winds.

## 39.3 Causes of Land Degradation

Although anthropogenic and military activities are the main causes of land degradation, aeolian processes, nature of surface sediments (soil type), and climatic conditions have played a significant role.

### *39.3.1 Anthropogenic Activities*

A leading cause of land degradation is the influence of the human population, which has led to land misuse and overexploitation of desert resources. Increase in population growth rate (3.8%) and welfare and the socioeconomic transformation in

**Table 39.1** Summary of the impacts of human activities on land degradation

| Activity | Immediate impact | Long-term impact |
|---|---|---|
| Excessive grazing | Depletion of biomass, forage loss, soil trampling, and sediment disturbance | Increase in dust and sand storms and in drifting sands, increase in rate of water erosion as a result of disappearance of the vegetation cover |
| Off-road vehicles and camping | Soil compaction, decrease in permeability, and destruction of vegetation cover | Increase in rate of wind and water erosion, development of sand drifts and active sand sheets, loss of soil fertility |
| Gravel quarrying | Breaking of the armor layer of pebbles and gravel, exposing finer sediments to wind erosion, disruption and rupture of surface and near-surface sediments, destruction of vegetation cover | Increase in dust and sand in downwind areas, disturbance of pattern of surface runoff, and loss of running water in pits and quarries |

general have led to a significant pressure on the available natural resources, leading to land degradation. Anthropogenic activities include excessive grazing (Omar et al. 1999), off-road vehicle traffic (Al-Dousari et al. 2000; Al-Awadhi 2001), spring camping (Al-Sudairawi and Misak 1999), and overexploitation of sand and gravel (Al-Awadhi 2001) (Table 39.1).

#### 39.3.1.1 Overgrazing

Several studies reported that overgrazing in arid regions could change plant community composition and reduce biodiversity (Shaltout et al. 1996; Li and Jiang 1997; Friedel et al. 2003; El-Keblawy 2003; Li et al. 2005; Tefera et al. 2007; El-Keblawy et al. 2009). Camel grazing affects over 90% of land on the Arabian Peninsula, of which 44% is severely or very severely degraded (Ferguson et al. 1998). Excessive grazing by camels is recognized as the single greatest threat to the inland desert ecology of the Gulf states (Hellyer et al. 2001; Gallacher and Hill 2006); Ghazanfar (2004) suggested that overgrazing has increased the proportion of unpalatable shrubs and dwarf shrubs. Brown and Porembski (1998) suggested that the current dwarf shrub ecology in northern Kuwait probably arose through tens or hundreds of years of excessive grazing. In Saudi Arabia and Kuwait, livestock enclosures were reported to show a rapid recovery in plant biomass (Zaman 1997; Barth 1999), and similar observations have been made in the United Arab Emirates (Khan 1980, 1981; Oatham et al. 1995). A field survey in January 2010 revealed that camel and sheep grazing was observed over the entire desert of Kuwait.

#### 39.3.1.2 Off-Road Vehicles Traffic

Off-road driving has long been recognized as a major detrimental factor, causing widespread damage to the vegetation and producing tracks on the soil surface (Adams et al. 1982; Brown and Schoknecht 2001). A number of studies have attempted to quantify the damage caused by off-road vehicles, particularly in the Mojave Desert in eastern California and southern Nevada (Wilshire and Nakata 1976; Webb 1982; Watts 1998). Apart from the obvious damage to shrubs, vegetation is also affected due to soil compaction in tracks (Adams et al. 1982; Wilhelm and Mielke 1988; Bainbridge and Virginia 1990; Rundel and Gibson 1996; Lovich and Bainbridge 1999).

In Kuwait, there has been a dramatic increase in off-road driving activity during the past decades. Vehicle tracks on the desert surface, often devoid of vegetation, are a common sight throughout many parts of the country. Off-road vehicle traffic is also responsible for soil compaction. At least 65% of Kuwait soils are affected by some degrees of compaction, which in turn inhibits the infiltration capacity of soils by 40–100% (Al-Awadhi et al. 2005b). Al-Dousari et al. (2000) reported that about 9% of the western area of Kuwait is assessed as highly compacted. The combined effect of the off-road vehicles traffic and the trampling caused by large herds of livestock may be responsible for the severe deterioration of the desert vegetation (Brown and Porembski 1997, 1998).

#### 39.3.1.3 Camping and Livestock Enclosures

One of the social traditions in Kuwait is camping in desert areas for about 2 weeks during spring time. In the early 1960s, camping activities were relatively limited and restricted to few locations. Also, livestock enclosures (mostly for sheep) were few and mostly scattered in the northern areas. During a survey conducted in the winter of 2010, it was observed that all desert areas are now crowded by camps, mostly permanent, and are in very close proximity. Also, animal enclosures for camels and sheep are now counted by hundreds. Within these locations, vegetation cover has totally been destroyed and the soils have been severely compacted.

#### 39.3.1.4 Quarrying

Gravel and gatch pits are extensively scattered over the desert of Kuwait. The extensive urban development over the past five decades created a great demand for gravel aggregate for housing projects and road construction. Gravel deposits are located within Al Dibdibba alluvial sheet in northern Kuwait, particularly within Al-Layiah and Kraa Al Marw ridges. Gravel quarrying started in early 1960s and continued till the 1980s. During this period extensive quarrying operations took place without any planning or regulation. This resulted in the occurrence of abundant open gravel pits that have drastically changed the natural landforms and eliminated the native vegetation cover over vast areas. Most of these gravel pits are located within the active wind corridor and, therefore, have significantly contributed to the abundance of drifting sands.

In addition, the overexploitation of the near-surface solidified calcareous and gypsiferous sands (gatch) for road construction and as fill material has resulted in the occurrence of hundreds of large pits over the desert of Kuwait. This is responsible for destruction of the vegetation cover, changes in the micro-topography of the desert areas, disrupting the surface water runoff system, and an increase of dust and shifting sand in downwind areas.

## *39.3.2 Military Activity*

### 39.3.2.1 The Gulf War

The Iraqi invasion of Kuwait on 2 August 1990 and the resulting Gulf War activities have left many scars on the fragile but balanced desert ecosystem of Kuwait (Holden 1991; Karrar et al. 1991; Al-Ajmi et al. 1994). The direct effect of these activities has been the mechanical removal of the native plants and extensive and severe disturbance of the soil (surface cover). The heavy bombing and trench digging during the war made the Kuwaiti desert even more vulnerable to intense and frequent sandstorms. In addition, maneuvers and off-road vehicle use caused severe compaction or loss of topsoil. The most severe aspect of Kuwait's environmental crisis was the burning of 727 oil wells and the gushing wells which made rivers of crude oil that ran into the low lands forming oil pools and lakes (Al-Besharah 1992). The presence of $SO_2$ in such a massive quantity at the time of the oil burning is thought to have led to the formation of acid rain which would have a damaging effect on vegetation entering the food chain (Al-Hassan 1992; Al-Houty et al. 1993).

It was estimated by El-Baz (1992) that about 30.6% of the land area of Kuwait was adversely affected by the Gulf War.

### 39.3.2.2 Postliberation Activities

After liberation, the first activity to be initiated was the removal of mines and ordinance from the Kuwaiti desert. This, in addition to the digging of numerous deep ditches for the detonation of collected ordinance, has resulted in the physical scraping of the topsoil and the associated biomass over much of Kuwait. This alternation has many detrimental effects, let alone the unknown impacts of the detonation process itself. Such operations have resulted in an extensive and severe rupture of the surface and near-surface sediments.

After the liberation of Kuwait, the following defense measures were implemented:

(a) The construction of a trench with a depth and width of 5 m along the entire northern and northwestern borders of Kuwait
(b) Installation of a chain link fence along the northern and northwestern borders to delineate a buffer zone of about 5 km wide

The trench acted as a backstop, trapping all migrating sands from southern Iraq. The buffer zone is considered as a protected area and, therefore, encourages the growth and flourishing of desert shrubs which also acted as a windbreak trapping migrating sands from the northern and northwestern directions. These measures have halted the sand supply from outside Kuwait, from southern Iraq. This is responsible from the enhancement of wind action on the loose surface sediments in Kuwait.

Several bund walls that extend for tens of kilometers; have been constructed mostly in an east-west direction. In addition, most of the military sites are fenced by similar bund walls. These are playing a significant role in the pattern and mode of both aeolian and fluvial sediment transport. They disrupt the continuity of sediment migration due to their interference with the near-surface aerodynamic regime. They act as windbreaks, accelerating soil erosion on the upwind side. Detailed study is recommended for thorough assessment of the impacts of these bund walls on soil stability, particularly in the northern areas of Kuwait.

### *39.3.3 Climatological Factors*

Climatological factors influence the land degradation processes through the following phenomena:

1. The scarcity and irregularity of rainfall. During the period from 1957 to 1998, total seasonal rainfall fluctuated between 23.1 mm (1963–1964) and 260.2 mm (1975–1976) compared with the average seasonal rainfall of around 115 mm.
2. The prevalence of drought periods (years with a remarkably low rainfall compared with the average). In 1962, for example, there was 27.2 mm of rain, in 1964 some 19.9 mm, in 1973 a total of 34.8 mm, and in 1987–1989 between 67.5 and 71 mm. During these drought periods, the vegetation cover deteriorated and the soil temperature increased. Consequently, desiccation processes cause shrinkage and cracking and the problem of sand encroachment.
3. The occurrence of intensive rainfall (65–105 mm in a single storm) and the consequent accumulation of very large amounts of dominantly sand and silt outwash material (Al-Sudairawi et al. 1999) have subsequently contributed to the sand supply.
4. The prevalence of strong northwesterly winds (maximum 30 m $s^{-1}$) during the dry season (May–September). This phenomenon encourages sand transport and soil erosion (Al-Awadhi and Misak 2000).

## 39.4 Conclusions and Recommendations

The present review and recent field surveys revealed that the biotic and abiotic components of the desert ecosystem of Kuwait have witnessed progressive severe and extensive degradation. This is manifested by the drastic deterioration of the vegetation cover, severe erosion and compaction of the soil, significant changes in micro-topography and imbalance in the surface sediment budget, and disturbance of the surface water runoff system which accelerate hydrological drought. The causes and driving forces for land degradation include uncontrolled irrational anthropogenic activities, aggressive military operations, and climatologic events. It is believed that both anthropogenic activities and military operations are the main causes of land degradation.

Mitigation of the adverse impacts of the aforementioned activities, rehabilitation of the degraded components of the desert ecosystem, and preservation of Kuwait's natural desert heritage require the implementation of a national action plan. The following are recommended measures:

Assessment of the present practice of grazing within a socioeconomic framework. The results of such an assessment should be used for the design of appropriate rules and regulations to maintain optimum soil conditions and allow maximum sustainable grazing capacity in Kuwait. The number of animals to be allowed for grazing should consider the present carrying capacity of Kuwait desert ecosystem.

Rational control of entertainment camping practices and off-road vehicles traffic. Suggested control measures should be based on assessment of the present situation and the carrying capacity of Kuwait desert ecosystem.

Reconditioning of the natural topography through filling quarries and pits and even removal of unnecessary bund walls and any man-made obstructions in order to reestablish the original aerodynamic conditions and therefore maintenance of the natural sand migration conditions while avoiding the imbalance in the surface sediment budget.

Reestablish the natural shrub vegetation through regeneration, restoration, and establishment of enclosures in selected areas for a certain period of time. However, it should be noted that recovery of the vegetation is presumably dependent on the extent of degradation when remediating measures are invoked, as well as climatic factors. In this regard use should be made of previous relevant studies including Charley and West (1975), Thalen (1979), Krueger (1990), Omar et al. (1990), Vetaas (1992), Le Houérou (1995, 1996), Tongway and Ludwig (1996), Ludwig and Tongway (1996), Zaman (1997), Brown and Porembski (1997, 1998), Shachak et al. (1998), and Brown and Al-Mazrooei (2001, 2003).

Sand encroachment problems resulted from the erection of development projects in the pathway of migrating sands; therefore, planning for these projects should consider the nature of aeolian sediment transport regime. Avoid as much as possible the stopping of creeping sands, with the use of passive control measures. If active control measures are required, it should be preceded by a thorough impact assessment.

Emphasis should be placed on policies, regulations and legislation, as well as national public education and awareness programs.

## References

Adams JA, Endo AS, Stolzy LH, Rowlands PG, Johnson HB (1982) Controlled experiments on soil compaction produced by off-road vehicles in the Mojave Desert, California. J Appl Ecol 19:167–175

Agnew C, Warren A (1996) A framework for tackling drought and land degradation. J Arid Environ 33:309–320

Al-Ajmi D, Misak R, Al-Dousari A, Al-Enezi A (1994) Impact of the Iraqi war machinery and ground fortifications on the surface sediments and aeolian processes in Kuwait. In: Proceedings of the international conference on the effect of the Iraqi aggression on the State of Kuwait, Kuwait, vol 3, 2–6 Apr 1994, pp 229–248

Al-Awadhi JM (2001) Impact of gravel quarrying on the desert environment of Kuwait. Environ Geol 41(3–4):365–371

Al-Awadhi JM, Al-Awadhi A (2009) Modeling the aeolian sand transport for the desert of Kuwait: constraints by field observations. J Arid Environ 73:987–995

Al-Awadhi JM, Misak RF (2000) Field assessment of aeolian sand processes and sand control measures in Kuwait. Kuwait J Sci Eng 27(1):156–176

Al-Awadhi JM, Al-Dousari A, Al-Enezi A (2001) Barchan dunes in northern Kuwait. Arab Gulf J Sci Res 18(1):32–40

Al-Awadhi JM, Al-Helal A, Al-Enezi A (2005a) Sand drift potential in the desert of Kuwait. J Arid Environ 63:425–438

Al-Awadhi JM, Omar SAS, Misak RF (2005b) Land degradation indicators in Kuwait. Land Deg Dev 16(2):163–176

Al-Besharah J (1992) The Kuwait oil fires and oil lakes – facts and numbers. In: Proceeding of the international symposium on the environmental and health impact of Kuwait oil fires, University of Birmingham, pp 12–15

Al-Dousari AM, Misak R, Shahid SA (2000) Soil compaction and sealing in AL-Salmi area, Western Kuwait. Land Deg Dev 11:401–418

Al-Hassan JM (1992) Iraqi invasion of Kuwait, an environmental catastrophe. Fahad Al-Marzooq Press, Kuwait

Al-Houty W, Abdal M, Zaman S (1993) Preliminary assessment of the Gulf War on Kuwait desert ecosystem. J Environ Sci Health 28(8):1705–1726

Al-Sudairawi M, Misak R (1999) Challenges and problems confronting the sustainable development in the desert of Kuwait. In: Proceedings of the 9th international conference on environmental protection is a must, Alexandria, Egypt

Al-Sudairawi M, Misak R, Kwarteng A, Al-Awadhi JM, Al-Dousari A, Gharib I (1999) Study of sand control at Kuwait Oil Company (KOC) operational areas of southeast, west and north Kuwait. Kuwait Institute for Scientific Research, report no KISR5550, Kuwait

Bainbridge DA, Virginia RA (1990) Restoration in the Sonoran desert of California. Restor Manag Notes 8:3–13

Barth HJ (1999) Desertification in the Eastern Province of Saudi Arabia. J Arid Environ 43:399–410

Brown G (2003) Factors maintaining plant diversity in degraded areas of northern Kuwait. J Arid Environ 54:183–194

Brown G, Al-Mazrooei S (2001) Germination ecology of Haloxylon salicornicum from Kuwait. Botanische JahrbucKher FuKr Systematik, Pflanzengeschichle und Pflanzengeographie 123:235–247

Brown G, Al-Mazrooei S (2003) Rapid vegetation regeneration in a seriously degraded Rhanterium epapposum community in northern Kuwait after 4 years of protection. J Environ Manag 68:387–395

Brown G, Porembski S (1997) The maintenance of species diversity by miniature dunes in a sand-depleted Haloxylon salicornicum community in Kuwait. J Arid Environ 37:461–473

Brown G, Porembski S (1998) Flora and vegetational aspects of miniature dunes in a sand-depleted Haloxylon salicornicum community in the Kuwait desert. Flora 193:133–140

Brown G, Porembski S (2000) Phytogenic hillocks and blow-outs as 'safe sites' for plants in an oil-contaminated area of northern Kuwait. Environ Conserv 27:242–249

Brown G, Schoknecht N (2001) Off-road vehicles and vegetation patterning in a degraded desert ecosystem in Kuwait. J Arid Environ 49:413–427

Charley JL, West NE (1975) Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems of Utah. J Ecol 63:945–964

Dregne HE (ed) (1992) Degradation and restoration of arid lands. Texas Technical University, Lubbock

Dregne HE, Kassas M, Rozanov B (1991) A new assessment of the world status of desertification. Desertification Control Bull 20:6–19

El-Baz F (1992) Preliminary observations of environmental damage due to Gulf War. Nat Resour Forum 16(1):71–75

El-Keblawy A (2003) Effect of protection from grazing on species diversity, abundance and productivity in two regions of Abu-Dhabi Emirate, UAE. In: Alsharhan AS, Wood WW, Goudie AS, Fowler A, Abdellatif EM (eds) Desertification in the third millennium. Swets & Zeitlinger Publisher, Lisse, pp 217–226

El-Keblawy A, Ksiksi T, El-Alqamy H (2009) Camel grazing affects species diversity and community structure in the deserts of the UAE. J Arid Environ 73:347–354

Ferguson M, McCann I, Manners G (1998) Less water, more grazing. ICARDA Caravan 8:9–11

Friedel MH, Sparrow AD, Kinloch JE, Tongway DJ (2003) Degradation and recovery processes in arid grazing lands of central Australia. Part 2: vegetation. J Arid Environ 55:327–348

Gallacher DJ, Hill JP (2006) Effects of camel grazing on the ecology of small perennial plants in Dubai (UAE) inland desert. J Arid Environ 66:738–750

Ghazanfar SA (2004) Biology of the central desert of Oman. Turk J Bot 28:65–71

Halwagy R, Halwagy M (1974) Ecological studies on the desert of Kuwait. II. The vegetation. J Univ Kuwait (Sci) 1:87–95

Halwagy R, Moustafa AF, Kamel SM (1982) On the ecology of the desert vegetation in Kuwait. J Arid Environ 5:95–107

Hellyer P, Al-Abed I, Vine P (2001) United Arab Emirates: a new perspective. Trident Press, London

Holden C (1991) Kuwait's unjust deserts: damage to its desert. Science 251:1175–1181

Howle S (1998) The long term environmental consequences of the Gulf War in northeastern Kuwait. MSc thesis, University of Massachusetts, Boston, MA, USA

Johnson DI, Lewis LA (1995) Land degradation: creation and destruction. Blackwell, Oxford

Karrar G, Batanouny KH, Mian MA (1991) A rapid assessment of the impact of the Iraqi-Kuwait conflict on terrestrial ecosystem, part II. The State of Kuwait. Report prepared for International Fund for Agricultural Development, Rome, Italy

Kassas M (1995) Desertification: a general review. J Arid Environ 30:115–128

Khalaf FI (1989) Desertification and aeolian processes in the Kuwait desert. J Arid Environ 16:125–145

Khalaf FI, Al-Ajmi D (1993) Aeolian processes and sand encroachment problems in Kuwait. Geomorphology 6:111–134

Khalaf FI, Al-Hashash M (1983) Aeolian sedimentation in the northwestern part of the Arabian Gulf. J Arid Environ 6:319–332

Khalaf FI, Gharib IM, Al-Hashash M (1984) Types and characteristics of the recent surface deposits of Kuwait. Arab Gulf J Arid Environ 7:9–33

Khan MIR (1980) Al bujair nursery in the western region. Emirates Nat Hist Group Bull 10:16–18

Khan MIR (1981) Al babha plantation. Emirates Nat Hist Group Bull 13:17–19

Krueger WC (1990) Animal range relations on arid and semiarid rangelands. In: Halwagy R, Taha FK, Omar SA (eds) Advances in range management in arid lands, 201–205. Kegan Paul International, London/New York, p 234

Kuwait Institute for Scientific Research (1999) Soil survey for the state of Kuwait, vol 1. Executive summary. AACM International, Adelaide, Australia, CD-ROM

Lal R, Stewart BA (eds) (1994) Land degradation, vol 11, Advances in soil science. Springer, New York

Lal R, Blum WEH, Valentin C, Stewart BA (eds) (1997) Methods for assessment of land degradation. CRC, Boca Raton

Le Houérou HN (1995) Eco-climatic and biogeographic comparison between the rangelands of the iso-climatic Mediterranean arid zone of North Africa and the Near East. In: Omar SAS, Razzaque MA, Alsdirawi F (eds) Range management in arid zones, 25–40. Kegan Paul International, London/New York, p 397

Le Houérou HN (1996) Climate change, drought and desertification. J Arid Environ 34:133–185

Lepers E, Lambin EF, Janetos AC, DeFries R, Achard F, Ramankutty N (2005) A synthesis of information on rapid land-cover change for the period 1981–2000. BioScience 55:115–124

Li JH, Jiang P (1997) The effects of different rotational grazing intensities on the soil, grassland and sheep productions in the northern Tianshan in China. Archivos de Zootecnia 46:301–310

Li JH, Li ZQ, Ren JZ (2005) Effect of grazing intensity on clonal morphological plasticity and biomass allocation patterns of Artemisia frigida and Potentilla acaulis in the Inner Mongolia steppe. N Z J Agric Res 48:57–61

Lovich JE, Bainbridge D (1999) Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. Environ Manag 24:309–326

Ludwig JA, Tongway DJ (1996) Rehabilitation of semiarid landscapes in Australia. II. Restoring vegetation patches. Restor Ecol 4:398–406

Maingnet M (ed) (1994) Desertification: natural background and human mismanagement. Springer, Berlin

Middleton N, Thomas DSG (1997) World Atlas of desertification, 2nd edn. Published for UNEP. Edward Arnold, London, p 182

Misak R, Al-Awadhi JM, Al-Sudairawi M (1999) Assessment and controlling land degradation in Kuwaiti desert ecosystem. In: Proceedings of the conference on the impact of environmental pollution on the development in the Gulf Region, Kuwait, 15–17 Mar 1999

Misak RF, Al-Awadhi JM, Al-Sudairawi M (2001) Assessing and controlling land degradation in Kuwaiti desert ecosystem. In: (Al-Sarawi M, Massoud M (eds). The Impact of Environmental Pollution on Development in the Gulf Region, Vol. II Environmental Public Authority, State of Kuwait, p209–223

Oatham MP, Nicholls MK, Swingland IR (1995) Manipulation of vegetation communities on the Abu Dhabi rangelands. I. The effects of irrigation and release from longterm grazing. Biodivers Conserv 4:696–709

Oldeman LR, Hakkeling RTA, Sombroek WG (1992) World map of the status of human-induced soil degradation: an explanatory note. ISRIC, Wageningen

Omar SAS (1991) Dynamics of range plants following 10 years of protection in arid rangelands of Kuwait. J Arid Environ 21:99–111

Omar SAS, Taha FK, Nassef A (1990) Ecological monitoring of vegetation in Kuwait's rangelands. In: Halwagy R, Taha FK, Omar SAS (eds) Advances in range management in arid lands. Kegan Paul International, London/New York, pp 57–71

Omar SAS, Shahid SA, Misak R (1999) Assessing damage magnitude and recovery of the terrestrial eco-system. Follow up of natural and induced desert recovery. Kuwait Institute for Scientific Research, Kuwait

Omar SAS, Briskey EJ, Misak R, Asem A (2000) The Gulf war impact on the terrestrial environment of Kuwait. In: Proceedings of international conference addressing environmental consequences of war: legal, economic and scientific perspectives, Washington, DC, USA

Omar SAS, Misak R, King P, Shahid SA, Abo-Rizq H, Grealish G, Roy W (2001) Mapping the vegetation of Kuwait through reconnaissance soil survey. J Arid Environ 48:341–355

Omar SAS, Bhat NR, Shahid SA, Assem A (2005) Land and vegetation degradation in war-affected areas in the Sabah Al-Ahmad nature reserve of Kuwait: a case study of Umm Ar Rimam. J Arid Environ 62:475–490

Ravi S, Breshears D, Huxman TE, D'Odorico P (2010) Land degradation in drylands: interactions among hydrologic-aeolian erosion and vegetation dynamics. Geomorphology 116:236–245
Reynolds JF, Smith S (2002) Do humans create deserts? In: Global desertification: do humans create deserts? Dahlem University Press, Berlin, pp 1–22
Rundel PW, Gibson AC (1996) Ecological communities and processes in a Mojave Desert ecosystem: Rock Valley, Nevada. Cambridge University Press, Cambridge, p 369
Safriel U, Adeel Z (2005) Dryland systems. Ecosystems and human well-being: current state and trends. Island Press, Washington, DC, p 948
Shachak M, Sachs M, Moshe I (1998) Ecosystem management of desertified shrublands in Israel. Ecosystems 1:475–483
Shahid SA, Omar SAS, Grealish G, King P, El-Gawad M, Al-Mesabahi A (1998) Salinization as an early warning of land degradation in Kuwait. Probl Desert Dev 5:8–12
Shahid SA, Omar SAS, Al-Ghawas S (1999) Indicators of desertification in Kuwait and their possible management. Desert Control Bull 34:61–66
Shahid SA, Omar SAS, Misak R, Abo-Rizq H (2003) Land resource stresses and degradation in the arid environment of Kuwait: an overview. In: Alsharhan AS, Wood WW, Goudie AS, Fowler A, Abdellatif EM (eds) Desertification in the third millennium. Swets & Zeitlinger Publisher, Lisse, pp 351–360
Shaltout KH, El Halawany EF, El Kady HF (1996) Consequences of protection from grazing on diversity and abundance of the coastal lowland vegetation in eastern Saudi Arabia. Biodivers Conserv 5:27–36
Tefera S, Snyman HA, Smit GN (2007) Rangeland dynamics of southern Ethiopia: (2) Assessment of woody vegetation structure in relation to land use and distance from water in semi-arid Borana rangelands. J Environ Manag 85:443–452
Thalen DC (1979) Ecology and utilization of desert shrub rangelands in Iraq. Junk, The Hague, p 430
Tongway DJ, Ludwig JA (1996) Rehabilitation of semiarid landscapes in Australia. I. Restoring productive soil patches. Restor Ecol 4:388–397
UNCED (1992) Managing fragile ecosystems: combating desertification and drought. Report no Agenda 21, Chapter 12: United Nations conference on environment and development
UNCED (1993) Agenda 21: earth summit – the United Nations programme of action from Rio: managing fragile ecosystems: combating desertification and drought. United Nations conference on environment and development, rio de Jenario, p 294
UNEP (1992) Status of desertification and implementation of United Nations plan of action to combat desertification, pp 1–15
Vetaas OR (1992) Micro-site effects of trees and shrubs in dry savannas. J Veg Sci 3:337–344
Wang X, Wang T, Dong Z, Liu X, Qian G (2006) Nebkha development and its significance to wind erosion and land degradation in semi-arid northern China. J Arid Environ 65:129–141
Warren A, Sud YC, Rozanov B (1996) The future of deserts. J Arid Environ 32:75–89
Watts SE (1998) Short-term influence of tank tracks on vegetation and microphytic crusts in shrub steppe habitat. Environ Manag 22:611–616
Webb RH (1982) Off-road motorcycle effects on a desert soil. Environ Conserv 9:197–208
Wilhelm WW, Mielke LN (1988) Winter wheat growth in artificially compacted soil. Canad J Soil Sci 68:527–535
Wilshire HG, Nakata JK (1976) Off-road vehicle effects on California's Mojave Desert. Calif Geol 29:123–132
Zaman S (1997) Effects of rainfall and grazing on vegetation yield and cover of two arid rangelands in Kuwait. Environ Conserv 24:344–350