Hdb Env Chem (2009): 141–170
DOI:10.1007/698_2008_5

Critical Assessment of the Environmental Consequences of the Invasion of Kuwait, the Gulf War, and the Aftermath

Samira A. S. Omar, N.R. Bhat, and Adel Asem

Abstract The invasion, occupation and liberation warfare severely impacted all aspects of desert environment, the soil, native vegetation and other natural resources of Kuwait. The State of Kuwait adopted immediate measures after liberation to restore the oil sector and clear the ammunition from the desert. Several studies were conducted by local and international organizations to understand the nature of the damage and quantify the extent of the damage to the environment and ecosystem. The results clearly indicate that these impacts still persist even after 18 years and in some cases, their hazard potential has increased. Research efforts were also made to evaluate various technologies to rehabilitate or restore degraded ecosystems and the environment. However, further research is needed to monitor long-term impacts of pollutants on the ecology and human health. The chapter discusses the findings of the investigations conducted on this subject and presents recommendations for large-scale rehabilitation of Kuwait's desert environment and ecosystem.

Keywords Biodiversity conservation, environmental rehabilitation, marine ecosystem, revegetation, terrestrial ecosystem

Contents

S.A.S. Omar (✉) and N.R. Bhat
Food Resources and Marine Sciences Division,
Kuwait Institute for Scientific Research, P.O. Box 24885, 13109 Safat, Kuwait
e-mails: somar@safat.kisr.edu.kw; nbhat@safat.kisr.edu.kw

A. Asem
Kuwait National Focal Point, P.O. Box 28311 13083
Safat, Kuwait

1 Introduction

The Gulf crisis started with the invasion of Kuwait by the Iraqi military on August 2, 1990. Although the United Nations called for an immediate, unconditional and complete withdrawal from Kuwait, Iraqi authorities instead of retreating from Kuwait continued to occupy and began to consolidate their position by erecting defensive structures in the desert and urban areas. The United Nations requested Iraqi authorities to withdraw from Kuwait by January 15, 1991. The further consolidation of defenses in and around Kuwait by Iraqi forces led to the Gulf War beginning with air raids for 43 days starting from January 16, 1991, followed by a 100-h ground operation beginning February 21, 1991. Kuwait was liberated on February 28, 1991.

Like in all armed conflicts, the desert and coastal environments of Kuwait were the main victims of this aggression. From the invasion through occupation and execution of liberation war, the Kuwaiti desert environment was abused mercilessly. Armored vehicles, tanks, and other military hardware moved unrestrained all over the desert. Hundreds of bunkers and foxholes were constructed, millions of mines placed in the desert and the Gulf waters, a large number of oil wells were detonated or exploded, millions of barrels of oil released into Kuwaiti waters and huge quantities of ammunitions were dropped in the desert [1, 2]. At the conclusion of war, Iraqi forces left behind huge quantities of solid wastes, such as scattered live and spent ammunitions, mines, crates from explosions and associated wastes and damaged military hardware. After the liberation, the State of Kuwait made tremendous efforts to demine the desert, refill the bunkers, foxholes, and underground shelters and collect unexploded ammunitions and debris left behind by the Iraqi military, which were later on detonated in large underground pits. These pits were subsequently refilled with foreign soil. The desert surface was completely destroyed with vegetation taking a heavy toll from these activities.

The impacts of the invasion and aftermath wars on the environment of Kuwait continued to cause some environmental and public health problems. In this chapter, the consequences of war, that occurred almost two decades ago, are presented here from ecological perspectives. The institutional efforts in rehabilitation of some damaged ecosystems in the terrestrial environment are discussed and evaluated in terms of the ecological recovery.

2 Ecological Setting

2.1 *Landscape and Climate*

Kuwait is a small, flat to gently undulating desert country extending between latitudes 28° 33′ and 30° 05′ N and longitudes 46° 33′ and 48° 30′ E in the north-eastern part of the Arabian Peninsula. It has a surface area of 17,818 km^2 covering the mainland and a number of offshore islands. The climate is characterized by extremely hot dry summers with long, intense sunshine hours and moderately cool short winters with occasional rain. The average daily maximum temperatures varied from 18.9°C (10-year average from 1996 to 2004) during January to 46.8°C in July [3]. The average daily minimum temperatures during this period ranged from 8.2°C during January to 28.3°C during July with the absolute temperatures dropping to almost zero during winter. The rainfall is minimal; averaging about 115 mm y^{-1} (fluctuates between 25 and 250 mm), but evaporation is very high, ranging from 3.1 to 21.6 mm d^{-1}. Rainfall occurs anytime between mid October and late April, but rainfall sufficient to induce germination of desert annuals normally falls in November. The relative humidity is low, and strong, dry and hot northwesterly winds prevail during summer, particularly in June and July. In a study involving various weather parameters during two periods (1962–1998 and 1999–2004), Salam and Mazrooei [4] concluded that the average maximum and minimum temperatures were 1.29 and 1.14°C higher during the 1999–2004 period compared to those during the 1962–1998 period. Using the precipitation (P)/potential evapotranspiration (PET) ratios, the climate of most GCC countries is classified as hyperarid (P/PET = < 0.05) to arid P/PET = 0.05–0.2) [5]. Le Houerou [6] distinguished a further climatic zone, the eremitic and included annual precipitation along with P/PET ratios to classify the climate of GCC countries. According to him, Kuwait and the northern part of Saudi Arabia cover the arid areas of the GCC.

2.2 *Soils*

Kuwait's soils are generally not well developed, predominately sandy, poor in organic matter and low in water retention capacity. The dominant soil orders are Aridsols (70.8%) and Entisols (29.2%) [7]. Kuwait Institute for Scientific Research

[8] identified and characterized eight great soil groups (Petrogypsids, Torripsamments, Petrocalcids, Haplocalcids, Aquisalids, Calcigypsids, Haplogypsids, and Torriorthents). Of these, the Petrogypsids occur on level to gently sloping plains formed on the sand and gravel deposits of the Dibdibah Formation. The Torripsamments, on the other hand, normally occur on extensive sand sheets in the central and south-east directions. While Calcigypsid and Haplogypsid soil types are found in the northern part of Kuwait, the Haplocalcids occur in the north, south and central part of Kuwait. Aquisalids are found in the coastal areas and in Bubiyan and Failaka islands [9, 10].

The land use is dominated by rangeland (75.12%), which is mainly used for grazing and recreational (camping) activities [7]. Oilfields and military activities occupy 7 and 4% of the total land areas, respectively.

2.3 Ecosystem Classification

Like in other Gulf Cooperation Council (GCC) countries, land resources in Kuwait are used for livestock grazing, water production, oil production, sand and gravel quarrying, agricultural production and camping/bird hunting during the winter season [11]. As soil becomes extremely dry during the hot dry summer, it is vulnerable to erosion, particularly when it is disturbed or becomes barren [12].

On the basis of variations in the habitat characteristics (landform and soil characteristics), the floristic composition and the dominant species, Omar [9] suggested six ecosystems: coastal plain and lowland ecosystem; desert plain ecosystem; alluvial fan ecosystem; escarpment, ridge and hilly ecosystem; wadi and depression ecosystem; and burchan sand dune ecosystem. Each of these ecosystems is characterized by a dominant plant community and associated with several other species.

2.4 Terrestrial Biodiversity of Kuwait

Kuwait's biodiversity comprises of 374 plant, 28 mammalian, 40 reptilian and 300 bird species [9, 13]. As in other arid and semiarid countries, out of the total 374 native plant species, annuals are the most dominant species (256 species), followed by herbaceous perennials (83 species), shrubs and under shrubs (34 species) and trees (one species) [9, 13]. Kuwait's native vegetation is of enormous scientific value because it represents a transition between semidesert and desert vegetation, highly vulnerable to human induced changes. It, therefore, serves as a valuable indicator of human perturbation, besides offering a valuable gene pool and plant material for drought and salt-tolerance research [14].

3 Pre- and Post-War Impact on Terrestrial Environment

The Iraqi invasion, occupation and the liberation warfare seriously disrupted many aspects of terrestrial and marine environment in Kuwait and made it one of humankind's worst environmental disasters (Table 1). The personnel carriers moved uncontrolled across the desert, hundreds of km of ditches were dug, thousands of makeshift shelters were erected and vast quantities of solid, semisolid and liquid wastes were left behind. Beginning February 17, 1991, Iraqi troops detonated 798 oil wells [1, 2, 15]. The oil wells with nearly 1,100 kg pressure per cm^2 discharged

Table 1 The impact of various damages caused during the Iraqi invasion, occupation and liberation war

Damage description	Impact	Sources
Number of damaged oil wells	798	[15]
Number of oil lakes	246	[23]
Area covered by oil released from detonated oil wells (km^2)	114	[15]
Area covered by tarcrete (km^2)	271	[15]
Amount of oil lost due to the oil fire (Mm^3)	159–239	[70]
Amount of sea water used to extinguish oil fire (million m^3)	7.5	[23]
Volume of contaminated soil in 110-km long trenches (m^3)	136,000	[15]
Total volume of oil-contaminated soil in oil lakes, trenches, oil spills and oil-contaminated piles (million m^3)	64	[15]
Volume of sulfur dioxide emitted daily (Gg)	22	[20]
Volume of soot discharged daily (Gg)	18	[20]
Number of military fortifications (000)	375	[23]
Total volume of excavated sediments (volume of excavated soil from military fortifications in the northern sector (million m^3)	16.7	[28]
Number of Iraqi tanks and tracked vehicles operated during the war	6,000	[28]
Number of allied forces tanks and vehicles operated during the war	5,145	[28]
Number of antipersonnel and antitank land mines (million until 1997)	1.60	[28]
Number of unrecovered mines	33,000	[119]
Amount of recovered ordinance (000 tons)	112	[28]
Amount of unrecovered ordinance (000 tons)	20	[120]
Total surface area impacted by Iraqi invasion, occupation and Gulf War (km^2)	5,460	[121]
Percentage of total area impacted by Gulf War	30.6	–

enormous quantities of oil onto the terrestrial environment, which flowed through natural slopes and damaged 114 km^2 of desert surface. Ultimately, the oil was accumulated in depressions forming over 300 oil lakes (Fig. 1) [1, 2, 16–19]. On evaporation of lighter oil fractions it formed thick sludge with an underlying layer of contaminated soil referred to as either "wet oil contamination" or "dry oil contamination" [15]. Currently, the wet contamination covering an area of 7 km^2 of the desert contains a surface layer of weathered crude, oily liquid or sludge sometimes covered by a thin hardened crust with an average depth of soil contamination of 63 cm. The dry contamination covers almost 100 km^2 and consists of thin crusts of highly contaminated material without wet oily layers or sludge. The average depth of contamination in these areas is 25 cm [2]. Besides oil lakes, an area of 8.5 km^2 is covered by piles of oil-contaminated soil and liquid oil, which were created during fire-fighting operations to prevent spread of oil. Furthermore, 110-km long trenches were dug along the Saudi Arabian border and filled with crude oil in an attempt to repel the advance of allied troops (Fig. 2). The oil in the trench penetrated deep into the profile and contaminated over 136,000 m^3 of soil, although subsequent backfilling of trenches with wind-blown sand left no signs of contamination on the surface [15]. The oil spill along the 750-km long pipeline constructed to carry the crude oil to these trenches also contaminated substantial volumes of surface and subsurface soil. Through satellite imaginary, field observation and soil sampling, it was estimated that 64-million m^3 soil was contaminated by oil lakes, oil contaminated piles, oil trenches and oil spills [2].

Fig. 1 Overview of an oil lake (wet contamination) nearly eighteen years after the detonation of Oil wells in Kuwait by the Iraqi troops

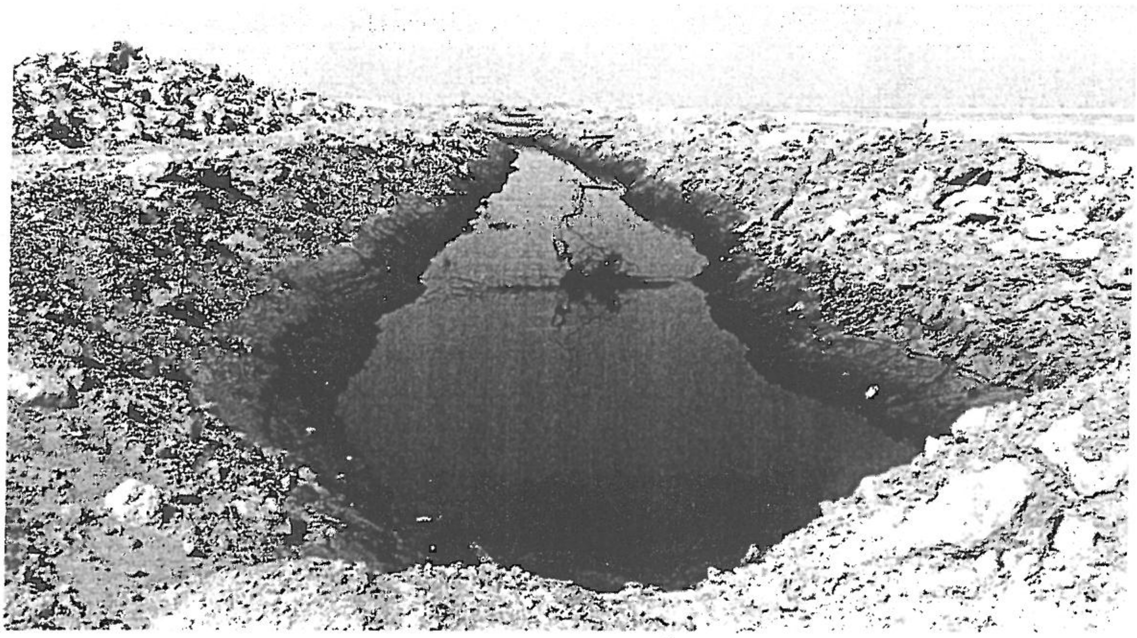

Fig. 2 Underground trenches filled with crude oil by the Iraqi Forces in 1991 during the invasion of Kuwait

The oil mist (known as "tarcrete" with an average thickness of contamination of 1–6 cm) and soot fallout (average depth of contamination is 0.2–0.8 cm) from the oil fire plumes covered vast areas of downwind terrestrial surfaces. The tarcrete was formed over an area of 271 km^2. In the desert 22 Gg of sulfur dioxide, 18 Gg of soot and thousands of tons of carbon monoxide and oxides of nitrogen were released from oil fires on a daily basis in the early stages [20, 21]. Besides, significant amounts of toxic metals and carcinogenic substances were released for several months [22]. The smoke from the oil fires not only carried toxic substances that were inhaled by animals and humans, but also darkened the atmosphere reducing the sunlight and ultraviolet rays reaching the soil surface. This affected the growth and reproduction in native flora and fauna [1]. More than 7.5-billion liters of seawater that was stored in 163 wellhead pits and used during the fire-fighting activities further compounded the damage to the terrestrial environment [23]. The materials used for backfilling these wellhead pits were contaminated with oil released from damaged wells. The impact of these activities on plants, wildlife, migratory birds, sand movement and water quality were substantial [1]. In addition, Iraqi forces spilled between 95×10^4 and 127×10^4 m^3 of oil into the Arabian Gulf [24]. The oil fires and the monstrous oil gushing that followed along with the swarm of plumes that they emitted captivated the world. Several nations cooperated in extinguishing the fires and cap the damaged wells [17, 25–27]. While the air cleared after the fires had been extinguished, this catastrophe left an adverse impact that still remains a national problem [2, 17, 20, 28].

Several research teams including the ones at the Kuwait Institute for Scientific Research (KISR) attempted to compare the environment [19, 28–37] and ecosystems [1, 2, 10, 11, 14, 23, 24, 38–42] during the pre-war and post-war periods. Comparison of remote sensing Landsat Thematic Mapper data from 1987 and 1995 indicated vast stretches of heavily and lightly contaminated areas [19]. Not only had the oil in the lake penetrated to varying depths, but also the addition of salty water to extinguish the oil well fires plus the rains that followed, washed oil pollutants downward as deep as 20 m in certain areas [19, 43, 44]. Omar et al. [2] determined the magnitude of damage by identifying the type (through field observation, laboratory analysis and Laser Induced Fluorescence measurements) and extent (using remote sensing, existing maps and field survey). These detailed investigations provided reliable information on the distribution, area, concentration and depth of contamination in the Kuwaiti desert.

The short- and long-term consequences of this disaster to the terrestrial environment can be grouped into six categories: (1) soil compaction due to increased movement heavy military vehicles throughout the desert; (2) surface sediment disruption due to the placement of mines, construction of bunkers, foxholes and other physical infrastructure related to war activities; (3) degradation of vegetation and wildlife habitat, (4) soil contamination with petroleum hydrocarbons and heavy metals, (5) ground water pollution; and (6) impact on marine environment and coastal ecosystems. There was also significant negative impact on public health as well [15].

3.1 Soil Compaction

Movement of heavy military machinery and personnel carriers in the open desert areas disrupted vegetation, wildlife and soils. Off-road transportation was concentrated in the southern border zone (about 175 km length, 10 km width), Ahmadi – Al Wafrah area, northeastern area and the area extending between Ali Al-Salem Airbase and Al-Abraq Farm (western area) [28]. It caused severe soil compaction to the majority of soil types. Depending on soil type, the degree of compaction and status of natural vegetation, soil compaction reduces the infiltration capacity of soils by 20–100% [2]. Consequently, the runoff erosion and terrain deformation increased [28]. Off-road movement of vehicles has long been recognized as a major deleterious factor causing widespread damage to the vegetation and causing tracks on the soil surface. Apart from obvious damage to shrubs, annual vegetation is also affected, as soil compacts in the tire tracks. Soil compaction reduces the ability of the soil to hold water and decreases pore space. The infiltration rate decreases while the penetration resistance increases manifold in compacted soils (Table 2) [45]. The roots in compacted soils encounter considerable difficulty in penetrating the surface layer [46] with noticeable repercussions for seedling establishment and growth.

Table 2 Impact of military fortification on physical properties of the desert soil

Military impact	Bulk density (dry) [g cm^{-3}]	Infiltration rate[a] [cm min^{-1}]	Penetration depth [cm][b]
Foxhole refilled with gatch pieces	1.71	7.8	42
Foxhole refilled with eroded sand	1.59	14.3	32
Area between foxholes	1.59	6.1	8
Sandy depressions	1.59	11.0	10
Refilled bunkers	1.40	13.4	>50
Refilled bunkers with stabilized ridge	1.58	8.9	2
Road track	1.77	0.9	0

[a] Infiltration rate was determined by double-ring infiltrometer [45]
[b] Penetration resistance was measured using bush penetrometer. The values correspond to the depth to which the penetrometer could move through the soil profile with <99 kg pressure cm^{-1}

3.2 *Sediment Disruption Due to Construction of Bunkers, Ground Fortification and Placement of Mines*

The eolian process in Kuwait is very active due to scarce, irregular rainfall, prevalence of strong northwesterly wind and extremely hot dry weather during summer months which increases the mobility of the sand [12, 47]. The severity of wind erosion depends on climatic factors, vegetation cover (type and density), soil erodibility and land use [28]. Prior to the Iraqi invasion, the protective desert lag surface stabilized the underlying loose soil sand layer in the northern desert, whereas the native vegetation cover blanketed the sand sheets in the southern part of Kuwait [48]. The Iraqi troops constructed more than 375,000 military fortifications, which included antitank ditches, berms, bunker trenches and pits [23]. Although the total area covered by military fortifications is only 6.25 km^2, they were scattered over a large area exposing soil and materials to wind erosion and affecting desert biodiversity, soil–water relationships and long-term soil productivity [49]. Using the satellite images, Kocha and El-Baz [48] showed that the military activities disrupted the lag deposits in the north and destroyed the vegetation cover anchoring the sand sheet in the south leading to huge mobilization of sand in approximately 17.2% of the total surface area of Kuwait. This led to catastrophic increase in sand movement and development of new eolian bodies [28, 48, 50–54]. This was clearly demonstrated by the increase in the sand drift rates from 393.7 kg per trap during July 1989–July 1990 to 691.1 kg per trap during November 1996–November 1997 in the Managish oil filed of Kuwait [55]. The increase in the sand movement was at a maximum in the NW direction (the amount of sand collected in the trap was increased from 9.46 to 161.98 kg).

The satellite images taken in 1985, 1989, 1992 and 1994 showed a sharp increase both in the number and aerial extent of sand dunes shortly after the Iraqi invasion [52, 53]. The average number of dunes formed was increased from 31 per year during 1985–1989 to 321 and 296 per year during 1989–1992 and 1992–1994, respectively. The overall dune size was also increased from 120 km^2 in 1985 to 220 km^2 in 1994.

During the occupation, the Iraqi forces excavated 1.042 million m^3 soil to construct ammunition bunkers, living bunkers and weapon pits [51]. The loose excavated material led to the formation of a new sand dune field that was detected for the first time in 1993 [28]. This dune field consisted of 30 barchan dunes (average dimension = 38.6 × 24.05 × 1.57 m) and domes. Similarly, Iraqi forces exposed 1.3 million m^3 of soil for constructing ground fortifications in the Southwest Burgan sand sheet area. This activity increased the thickness and extent of the sand sheet resulting in the encroachment of farming areas and desert facilities in Wafra [54].

Environmentally, demining operations caused a wide variety of damage including: (1) soil pollution by residual explosives; (2) loss of natural vegetation and wildlife habitats; and (3) surface deformation and soil loss. A relative scoring criteria showed that demining operations had moderate distribution (aerial extent), severe magnitude and slow recovery rates indicating that this activity had a high impact on the terrestrial environment [2].

3.3 *Impact on Ecological Components*

The main components of Kuwait's terrestrial ecosystem include landforms, climate, soils, florestic composition and wildlife activities. Based on the habitat (landform and soil characteristics) and florestic composition, Omar [9] suggested six ecosystems (coastal plain and lowland; desert plain and lowland; alluvial plain, escarpment, ridges, hilly; wadi and depression; and barchan sand dune). The landform and soil characteristics (physical, chemical and biological) influence the distribution, abundance and performance of native plants. Prior to the Iraqi invasion, Kuwait's native vegetation was exposed to harsh climatic conditions (extremely high temperature, severe drought and sand encroachment), increased human interference and overgrazing. During the Iraqi occupation and the Gulf War they were subjected to additional pressures from placement of mines, construction of bunkers, fallout of oil mists, oil flows through the natural slopes and contours forming oil lakes in depressions, formation of tarcrete and movement of heavy vehicles. In general, the affected areas had poor vegetative cover, differed widely both in species composition and ground coverage. Vegetation status, abundance even within a small area and growth and productivity were adversely affected by military activities (Table 3) and oil pollution. Other studies that measured the impact of oil pollution and military activities on ecosystem components also reported significant adverse effects in the number, composition and coverage in the desert [2, 11, 14, 32, 39, 40, 45, 56–60].

Table 3 Impact of military activities and oil pollution on different terrestrial vegetation types

	Average scores for various activities related to Iraqi occupation					
Plant communities	Off-roads movement	Ground fortifications	Oil trenches	Oil lakes	Fire-fighting	Demining operations
Centropodietum	5	1	0	0	0	1
Cyperetumn	2	3	2	4	4	3
Halophyletum	4	3	2	0	1	2
Haloxyletum	2	4	1	2	2	3
Panicetum	0	4	0	0	1	2
Rhanterietum	0	3	0	3	3	2
Stipagrostietum	5	4	2	2	1	4

Source: [23]. *Scoring scale*: 5 = very severe (>75% damage); 4 = severe (75–50% damage); 3 = moderate (50–25% damage); 2 = slight (25–10% damage); 1 = very slight (<10 % damage); 0 = no damage

Damage to the ecological components of the Kuwaiti desert during the Iraqi occupation and liberation war include:

- A number of plant communities have become either rare or endangered by the Gulf War crisis [9, 61] and there is a significant shift in the natural plant succession process due to selective establishment and/or growth of only certain species [9, 14].
- Eradication of grasses and drying up of cultivated trees because of abandonment of agricultural farms and forced neglect.
- Increased sand encroachment on agricultural farms and animal production facilities because of ceasing of maintenance operations (sand removal).
- Deterioration of vegetation and wildlife habitats through overgrazing inside protected areas, such as Sabah Al-Ahmad Nature Reserve and other protected facilities, due to the destruction of the fences during the occupation of Kuwait.
- Significant reduction in species composition, frequency and herbage production in several native plants due to the contamination of the soil with petroleum hydrocarbons [2, 14, 39].
- Trapping of birds and other animals in the oil lake [1, 62, 63]. Alsdirawi [62] reported that the oil sludge killed the upper life forms by its toxicity and killed the deep life forms by suffocation. Because oil lakes were mistaken for water bodies, migratory birds and insects ended up tragically as corpses scattered in and around the oil lakes.
- High levels of heavy metals in plants that were covered by oil mist and grew in oil-contaminated soils [56]. Plants that were subjected to aerosol deposits are therefore not suitable for grazing.
- Even 12 years after the oil spill, sand lizards (*Acanthodactylus scutellatus*) and their prey (ants) in oil-polluted sites contained 26.5–301 and 6.2–82.1 ng g^{-1} of total PAHs, respectively [63]. These results point to persistence of significant threats to wildlife in oil-polluted areas.
- In a study on the effects of oil pollution on the behavior of the sand lizard (*Acanthodactylus scutellatus*), Al-Hashem et al. [64] reported significant behavioral

changes in terms of early daily emergence, faster eating habits and shorter basking time in oil polluted areas (tarmat and sooty sites) than in clean sites.

Native plant seeds are usually dispersed over a great distance in the desert and remain viable for several years allowing them to germinate only when the conditions are right. Deep sandy soils that are protected from mobile sand movement, allow substantial buildup and retention of seed banks. This was substantiated by the observation made by Zaman [65] that *Rhanterium* plants are capable of building a large seed bank in deep sandy soils that remain viable for 4 years or more. In contrast, minute seeds are blown away from compacted or crusted surfaces by the wind. Even if the seeds are present, the compacted sites do not allow them to be properly oriented, a condition critical for germination to occur in this species [66]. In plants that dispersed their seeds near to the source, subsequent seed germination is inhibited if the soil is contaminated with oil. However, the ecological significance of the disruption in seed dispersal and inhibition of seedling emergence due to oil pollution and military activities requires further investigation.

During 1991 when the oil wells were still burning, the soot and particulate matter formed the "black clouds," which altered the microclimate (temperature and rainfall) in the desert. This, in turn, affected the survival rates and the phenological progression in a number of native plants [39]. For example, the survival rates for perennials like *Rhanterium epapposum* and *Haloxylon salicronicum* in soot-covered sites was almost 100%, but it was only 10% for the perennial forb, *Moltkiopsis ciliata.* Similarly, only 50% of *Cyperus conglomeratus* and *Stipagrostis plumosa* survived in soot-covered sites [1]. In contrast, only *H. salicornicum* survived in oil-mist covered sites, whereas oil-logged sites were devoid of any vegetation [39]. Herbage and seed production was also affected by the alteration in the microclimate.

A number of protected areas (Sulaibiya Field Station, Sabah Al-Ahmad Nature Reserve, Jahra pond, Doha Reserve) were established during the pre-war period to preserve the biodiversity of Kuwait. Baseline information required for restoration of natural resources and native biodiversity was compiled during the pre-war period [13]. However, during the occupation, the boundary fence was knocked down making them vulnerable to open grazing and human intrusion; trenches and foxholes were constructed and mines were placed in these protected areas. The valuable information gathered from 20-years of range management research and conservation efforts were completely lost during the invasion [2].

Several researchers all over the world have shown that severely disturbed soils are very slow to recover and in turn, have significant long-term effects on ecosystem recovery and functioning [67–69].

3.4 *Impact of Oil Contamination*

During 1990 to 1991, the Kuwait desert environment was polluted by the formation of oil lakes and oil-contaminated soil surfaces from the sabotage of the oil infrastructure by the retreating Iraqi troops. More than 798 functional wells were detonated resulting in release of large quantities of oil which flowed along natural terrain and contaminated an area of 110 km^2 [15, 23]. The amount of oil lost due to both the fires and oil flows was calculated to be approximately 1.0–1.5 billion barrels [70]. Almost 70% of the operational oil wells occur in the Greater Al-Burqan area, which includes the Maqwa, Ahmadi and Burqan oil fields. Here, there were 636 oil wells, of which 491 were burning, 33 were gushing, and 66 were damaged [71]. It was estimated that approximately 300 oil lakes of various sizes covered more than 49 km^2 of surface area [17]. Of these, there were 45 major lakes in Burqan and 23 major lakes in Maqwa and Ahmadi oil fields combined. Oil mist (Tarcrete) and soot covered an additional 1,772 km^2 of the land surface of Kuwait [19, 50, 72]. The majority of the lakes and oil-polluted surfaces were created in the Burqan oil field and surroundings areas [73]. The total volume of contaminated soil was estimated as 40 million m^3 [15].

Oil trenches are oil-filled defensive facilities prepared by Iraqi troops in the southern border zone of Kuwait and along the northeastern coast. The construction of 110-km long trenches along the Saudi Arabian border and the 750-km long oil transit system to deliver the oil to these trenches resulted in the destruction of vegetation, soil loss, surface deformation and micro-relief changes (Fig. 2) [2]. Surface oil spills, contamination of soil in the deep layers, ground water pollution, degradation of habitat quality and loss of native vegetation and wildlife occurred during and after the filling of these trenches with crude oil (Table 4). It was estimated that 136,000 m^3 of soil was contaminated with oil in this process. Although the contamination is not now visible on the surface, oil has penetrated deep into the soil profile [2].

The concentration of soot falling within a 50 km radius of the burning wells was estimated to be 100–200 g m^{-2} or 1–2 t ha^{-1} [74]. Contaminant penetration in some areas was generally much shallower than in areas affected by oil lakes. In addition, the exposure of the thin veneer of contamination has caused the degradation of the target contaminants and resulted in the reduction of the overall organic constituents. However, the residual contamination still contains a significant amount of persistent organic contaminants, such as polycyclic aromatic hydrocarbons [35]. While the

Table 4 Impact of oil trenches on the desert environment as observed in 2000

	Impact on the desert environment							
Activities	1	2	3	4	5	6	7	8
Construction of oil transit system	E	E	E	E	E	E	NE	NE
Construction of trenches	E	E	E	E	E	E	NE	NE
Filling of trenches with oil	E	NE	NE	NE	NE	NE	E	E
Oil recovery after liberation	NE	NE	NE	NE	E	NE	E	NE
Backfilling of trenches	E	E	E	E	E	NE	NE	NE

E, existing; NE, not existing. 1, Loss of native vegetation and wildlife; 2, exposure of fine sediments to wind erosion; 3, rupture of desert lag; 4, alteration of micro-relief; 5, surface compaction; 6, bed rock fracturing; 7, oil contamination; 8, contamination of grounvd water with oil natural degradation in tarcrete-affected areas reduced the oil contamination by up to 70% [75], the remaining portion consists of stable oil residues that are not degraded by natural processes. The decomposition of the oil pollutants in the subsoil layers and oil-soaked *gatch* layer was not significant [75].

When the wells were detonated and damaged, the oil continued to flow onto the surface, creating oil lakes, until these wells were capped. A significant portion of the recoverable oil was collected from the lakes, but the lake beds still remain heavily contaminated. Often a thicker layer exists at the bottom of the lake from where the oil has migrated under the influence of gravity and rainfall. The crude oil in these lakes has been exposed to harsh atmospheric conditions, resulting in the loss of volatile hydrocarbons, and has undergone other physical and chemical changes. With time, the lighter oil evaporated, oil mist hardened, and smaller and shallower oil lakes dried up and continued to disintegrate gradually [76]. Currently, the wet contamination (lakes with oily liquid or thick sludge) (Fig. 1) and dry contamination (lakes with thin crusts of heavily contaminated material without the wet oily layers or sludge) (Fig. 3) cover an area of approximately 7 and 100 km^2, respectively [15]. There was some oil migration to new locations as a result of occasional strong rainstorms and flash floods.

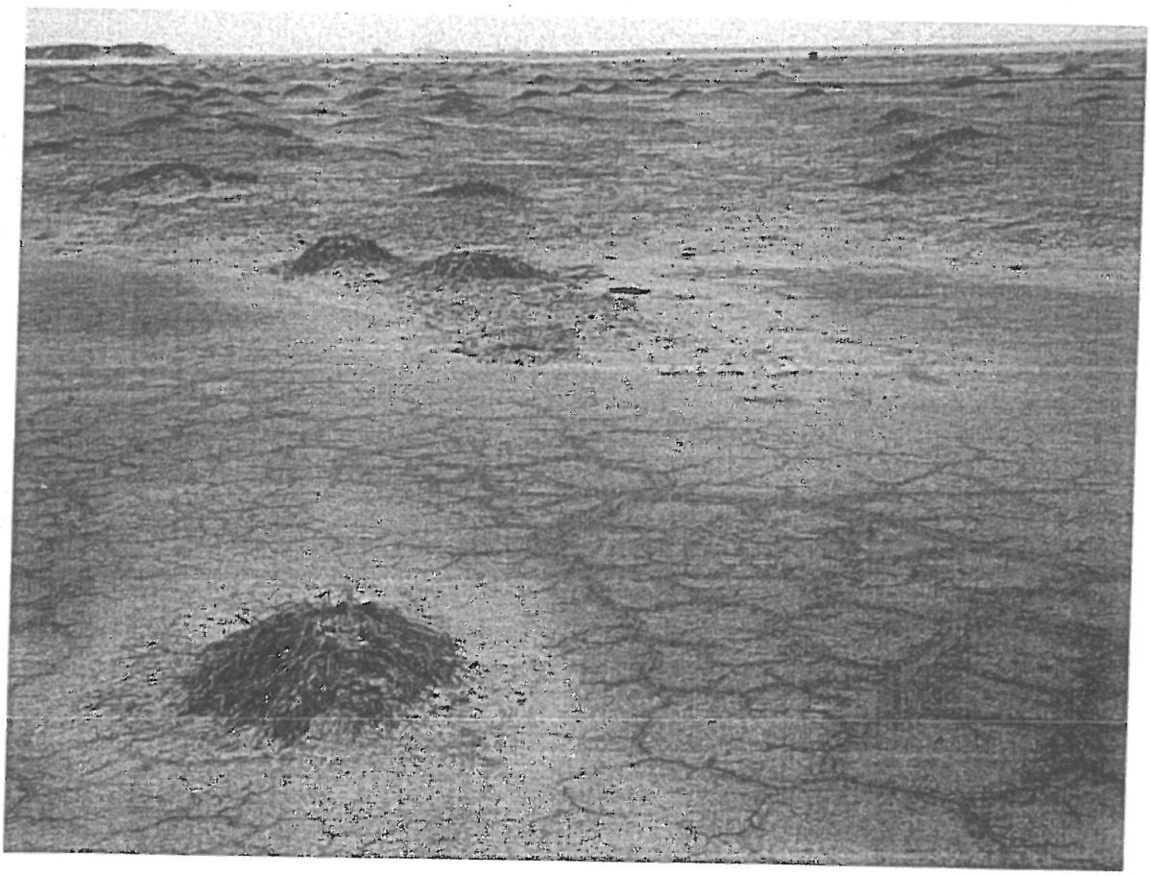

Fig. 3 Dry oil lake at Al Burgan Oil Field nearly eighteen years after the oil well detonation by the Iraqi troops (notice the dead plants in the area)

The terrestrial environmental damage was more than the formation of oil lakes, damage also occurred to vegetation, wildlife, soils and water resources. The initial damage to vegetation and wildlife included complete mortality of the vegetation and wildlife found trapped within the oil lakes, and changes in plant and faunal communities in areas near oil lakes. Even today, animals (especially migratory birds) are killed in the oil lakes when they land there inadvertently. This has caused a radical change in habitat quality, with implications for the whole ecosystem. Atmospheric deposition from the burning oil could have dispersed trace pollutants over a wide area, resulting in long-term impacts associated with the persistent presence of these pollutants in surface and subsurface soils [56]. There is a possibility that contaminants have been transmitted to humans through the food chain through grazing animals and marine life.

The indirect impacts of oil in soil include effects on the soil–water relationship. Oil tends to accumulate in pores between soil particles, which are occupied by oxygen in the normal soil. Such anaerobic conditions can lead to microbial generation of phytotoxic compounds and the soil will be unable to maintain aerobic micro-organisms vital for sustaining plant root activities. The oil also decreases the capacity of the soil to store moisture and air [50].

Although most of the oil from the lakes has been removed or has been the subject of heavy weathering, the lakebeds still contain a large amount of oil, which cannot be easily removed. Analysis of samples indicated that the composition of the oil in the lakes continues to change [77]. The chemical composition of weathered oil showed a decrease in aromatic compounds, and an increase in resins and higher polycyclic aromatic hydrocarbons. This increases the hazard potential of oil lakes. Heavily contaminated soils may eventually erode and be resuspended and transported to populated areas during dust storms and could cause health hazards [35]. There is also the possibility of contaminating soil with heavy metals, particularly nickel, vanadium, chromium, and lead.

Another problem related to the oil well fires was the extensive amount of saline water used for fire fighting. The fire-fighting teams used more than 1.5 billion gallons of seawater or brackish water [23]. One-hundred and sixty three water lagoons the size of small lakes were prepared to support fire-fighting operations. Analysis of soil samples from these areas showed the presence of high total dissolved salts (TDS) and sodium concentrations. Increased soil salinity is known to inhibit the reestablishment and growth of native vegetation.

3.4.1 Open Burning and Open Detonation Sites (OB/OD)

Following the liberation, the State of Kuwait undertook extensive explosive ordnance detonation (EOD) operations in which large quantities of unexploded munitions were destroyed through open burning (OB) or detonation in underground pits (OD). This resulted in the contamination of soils with nitroaromatics, nitrosamines, and nitrate esters. Exposure to these substances can cause a variety of toxic effects in humans and can affect the natural ecosystems.

3.5 Impact on Groundwater Resources

Kuwait received above-normal rains in the initial years of the post-war period (1991–1995). Therefore, groundwater pollution occurred due to the direct seepage of oil from the oil lakes and/or leaching of combusted or partially combusted materials deposited on the soil surface [1, 43, 78]. Leakage of oil from damaged oil wells deep in the soil remains a continuing potential threat to the ground water aquifer. PAHs in the soil can migrate during the rainy periods and contaminate the aquifer.

The two main fresh water aquifers in Kuwait (Rawdhatain and Um Al-Aish), because of their close proximity to the soil surface (approximately 20 m from the soil surface) are highly vulnerable to any pollution. Groundwater samples taken from these areas during January–June 1992 and July–October 1992 were found to contain Nickel (Ni) and Vanadium (V) between 1 and 833 ppb and 1 and 73 ppb, respectively [35]. Hydrocarbon concentration during January–June fluctuated between 1 and 190 ppb. The application of excess water to the soil surface during fire fighting might have resulted in the rise of the groundwater table, thereby exposing the aquifer to oil pollutant chemicals and heavy metals. The contaminated surface and subsurface soil horizons would continue to serve as potential sources of pollutants for a long-period and allow infiltration of water-soluble pollutants from the oil to deeper layers along with rain water [35, 79].

3.6 Impact on Marine Environment

Although the discovery of petroleum deposits has completely changed the economy of GCC countries, the marine environment and coastal ecosystems form an important renewable natural resource base in the region. The seawater is also the main source of freshwater from the desalination plants. Therefore, the Gulf marine environment is important in fulfilling social, economic, strategic and developmental objectives of Kuwait and other countries in the region. The marine environment is influenced by natural processes and human activities [24, 41, 80, 81]. The Iraqi invasion in 1991 aroused much concern because of the release of between 190×10^4 m^3 (12 million barrels) of oil into Persian Gulf waters [15]. The oil aerosols, soot, toxic combustion products and oil-derived heavy metals from the oil fires were found to be causative factors for the environmental marine pollution [74, 82]. The ignition of such oil fire fallout in the coastal water was found to surpass those quantities of oil directly released from the sea island terminals [83]. Sedimentological and chemical analyses of 84 bottom sediment samples from the entire Gulf area after the 1991 Gulf War was carried out as part of an international cooperative program. This program fell under the auspices of the Regional Organization for the Protection of the Marine Environment (ROPME), the Intergovernmental Oceanographic Commission (IOC), and the National Oceanographic and Atmospheric Administration (NOAA) of the USA [84]. There are also several studies dealing with the marine environment before and after the Gulf War [36, 81, 85–90]. In addition, there are some comprehensive reviews [24, 91] and predictions made on the recovery of the regions' marine environment [92].

According to [91], the overall damage to the subtidal marine ecosystem was less than initially expected since: (1) the spilled oil moved quickly to the south and became stranded on the Saudi Arabian coast causing significant damage to the intertidal zone there. (2) There was a significant reduction in the chronic discharge and/or oil transport due to reduced oil industry activities in the initial years after liberation (1991–1993). (3) Acclimation of Gulf oil pollution and the ability of the marine ecosystem to withstand high concentrations of petroleum hydrocarbon pollutants; and (4) high rates of degradation and transformation of pollutants due to high temperatures, intense solar radiation and virulent microbiological populations in Kuwait's marine water. However, war-related activities imposed an additional ecological burden on the already stressed coastal ecosystems [24]. Considerable ecological recovery of the coastal areas from the Gulf War oil spill was noticed within 5 years; however, complete recovery of mangroves and salt marshes would take much longer [24, 92, 93]. Most of these surveys have focused on primary pollutants including certain heavy metals. The Gulf environment, particularly in Kuwait, could have been exposed to other hazardous materials, such as PCBs from destroyed transformers, different war materials (bullets, shell fragments, etc.) and secondary pollutants produced during the environmental weathering of oil [91]. These weathered compounds from the desert surface could pollute the marine environment over a long period.

Physical destruction of beaches by construction of trenches, placement of mines and other defense installations not only damaged the intertidal zone, but also posed a severe threat to turtles nesting on the islands [41]. However, a survey of the coral reef islands of Kubbar, Qarre, and Umm Al-Maradem off the Kuwaiti coast by [94] did not show any significant damage to coral reefs due to oil spills in these areas.

3.7 *Emerging Technologies for Assessment of Oil Pollution Damage*

A number of technologies, such as the use of growth bands of coral reefs as biomarkers for oil pollution, satellite imaginary and thermal remote sensing, SIR-C/X-SAR, laser-induced fluorescence (LIF) and fluorescence fingerprinting are now available for assessing the impact of oil pollution on the environment [2, 95–99]. McGlade et al. [100] suggested the use of the "Fuzzy logic" expert systems to provide better insight into the environmental conditions, whereas [96] recommended the use of SIR-C/X-SAR to detect and map buried oil lakes. Accurate knowledge of the location and the extent of these oil lake bodies are of great importance to resource recovery and environmental remediation efforts.

Because sand lizards (*Acanthodactylus scutellatus*) constitute an important component of terrestrial ecosystems by forming an important link between invertebrate prey (insects) and predatory vertebrates (snakes, birds) and are widely distributed in the desert, their behavioral changes have been used as bioindicators to assess the lasting impacts of oil pollution on terrestrial ecosystems in Kuwait [64]. The changes in the daily morning emergence, eating and basking activities have been considered sensitive, nondestructive indicators of oil pollution.

Establishment of regional and national databases and spatial models are important in the assessment/monitoring of long-term consequences of the Gulf War on the environment [92].

4 Reversing the Damage to the Terrestrial Environment

The deliberate release of oil into the Gulf waters, capping of gushing oil wells, extinguishing blazing oil fires, refilling of trenches, bunkers, foxholes and other ground fortifications, eliminating health hazards of oil pollution and demining were some of the many problems the State of Kuwait had to address immediately after the liberation in February 1991. Nowhere else in the world have the scientists and engineers had to deal with environmental terrorism of this magnitude. To address such an unprecedented situation effectively, the State of Kuwait had to seek international cooperation and mobilize all its resources to redevelop its own national capacity. Because of the wholehearted cooperation of Kuwaiti people, governmental and nongovernmental organizations, and dedicated teams of local and international scientists and engineers, the task of putting the flames out was completed within 258 days (the last well fire was extinguished on Nov. 6, 1991). However, during this period, huge quantities of soot, toxic gases and particulate matter had already entered the atmosphere and settled over the desert surface and marine area. The problem of oil lakes was another continuing challenge not experienced anywhere in the world before, though minor accidental oil spills have been reported. A significant part of the lighter hydrocarbon fraction had evaporated, while a major portion of the oil from the oil lakes was recovered by Kuwait Oil Company and Kuwait Petroleum Corporation [101]. Still huge quantities of oil remain in the desert in the form of oil-soaked soil, sludge, tarcrete and continue to affect the soil, biodiversity and environment. Therefore, a number of studies were and still are being conducted to evaluate various rehabilitation and restoration options to restore the natural resources and environment to its original state. The measures adopted by the State of Kuwait to restore and rehabilitate areas impacted by various activities are summarized below.

4.1 Rehabilitation of Areas Damaged by Ground Fortification and Mining

As described in the earlier section, Iraqi forces constructed several thousands of fortifications throughout the Kuwaiti desert. This activity disrupted the desert pavement, vegetation and micro-relief and exposed large volumes of fine sediments to wind erosion. This led to the formation of sand dunes and an increase in the frequency of dust storms and drift formation. In the post-liberation period, the Ministry of Defense dismantled these fortifications, cleared the contents and backfilled with soil. To mitigate the long-term impact, it is proposed to remediate the backfilled areas by spreading a thin layer (2.5 cm) of gravel over the damaged surface. This measure is expected to stabilize the surface and facilitate the reestablishment of native plants. To minimize the long-term impact of the Iraqi invasion on eolian processes in Kuwait (deflation, transportation and accumulation of sediments), Al-Ajmi et al. [50] suggested the construction of a fence around the heavily damaged areas to protect them from off-road traffic movement to allow natural recovery of the soil and recolonization by native plants.

A team of professionals from seven countries made rigorous efforts to clear land mines and military ordinance. The process is complete for the most part, but there have been occasional instances of finding live mines particularly in the border area. Unexploded munitions have been gathered and disposed of by open burning or detonated in underground pits (OB/OD program). However, the long-term monitoring of their impact on the environment is required to minimize any detrimental effects [2, 102].

4.2 Rehabilitation of Areas Damaged by Wellhead Storage Pits

Areas covered by the 163 wellhead storage pits are proposed to be rehabilitated by removing the berms around the pits, excavating the contaminated soil and treating it to remove the contamination and backfilling the pits with the treated soil. Application of a thin layer of gravel will stabilize the surface and facilitate the recovery of native vegetation.

4.3 Rehabilitation of Tarcrete-Covered Areas

An area of approximately 270 km^2 in the Kuwaiti desert is covered by tarcrete contamination. The tarcrete layer can be removed, treated to remove oil contamination and disposed of safely. After the removal of tarcrete, the surface can be stabilized with a thin layer of gravel. Alternatively, the tarcrete layer can be broken up manually with application of organic amendments in holes (fully decomposed biosolids, composts, etc.) to provide additional nutrients, enhance soil processes and improve the moisture retention capacity of the soil to accelerate the natural recovery process. Reseeding with native plants can further accelerate the recovery process.

4.4 Bioremediation of Oil-Contaminated Desert Soil

The oil in the lakes has lost most of the volatile hydrocarbons and undergone physical and chemical changes [103, 104]. The oil lake areas currently are covered by an oily sludge under which oil has migrated to varying depths under the influence of gravity and rainwater. The natural biological, photo-chemical, and physical processes (passive remediation) can remediate large areas contaminated with not more than a 1-cm layer of airborne-deposited soot and unburnt oil droplets [105]. Although such processes can clean contaminated soil to the levels that permit growth of desert plants, the reduced pollutant levels will still be a threat to the environment [105]. Soils contaminated up to 2–50 cm depth and heavily contaminated lake beds do not degrade naturally or can not be left to the action of nature. Therefore, a joint research program between Kuwait Institute for Scientific Research and Japan's Petroleum Energy Center was initiated in 1994 in which various biological methods (land farming, windrow composting piles and static bioventing piles) for remediation of oil lake beds were evaluated [104]. The authors have reported 82.5 and 90.5% reduction in total petroleum hydrocarbons (TPH) and total alkanes, respectively within a 12-month period. Of the three methods, the bioventing soil piles were found to be the most cost-effective method. However, bioremediation is not suitable for treating heavily contaminated soils. The best way of dealing with heavily contaminated soil is to dispose of it in landfills or use other methods like high-temperature thermal desorption (HTTD).

Oil-contaminated soil can also be treated by passing through a rotary kiln where it is allowed to remain for sufficient duration to achieve a soil temperature sufficient (between 371 and 482°C) to volatilize the contaminants (HTTP). The combustion gas in the HTTD system remains either in direct contact with contaminated soil (direct-fired high-temperature thermal desorption) or is separated from the vaporized petroleum hydrocarbons or volatilized residue (indirect-fired HTTP). The treated soil is then cooled and passed through the rehydration unit before being screened and stockpiled. The HTTD-treated soil is black in color, completely sterile, and lacks soil structure [15]. It is also expensive compared to bioremediation.

Limited studies have been conducted on the use of plants for rehabilitating oil-contaminated soils and on the effects of uptake of petroleum hydrocarbons by these plants. Further research is required on the applicability of phytoremediation methods for restoration and rehabilitation of oil-contaminated soils in the Kuwaiti desert.

The areas surrounding the oil lakes recovered gradually on their own and supported limited native vegetation. This was evident in the Landsat Thematic Imaginary analyzed in 1995 [30]. However, some of the oil lake beds that were covered by veneers of sand were not visible in the satellite images, but still pose hazards to the desert environment and the ecosystem. The extent and nature of contamination has since been estimated more accurately and these data are being used by the Kuwait National Focal Point (KNFP) in developing the national action plan for rehabilitation of oil-contaminated soils [2].

4.5 Rehabilitation of the Terrestrial Ecosystem

Degraded desert ecosystems like that of Kuwait can be regenerated by either restoration or rehabilitation. Restoration implies returning to original rangeland (prestine) status, whereas rehabilitation would invariably result in a vegetation type that is different from the original one [106]. Restoration is very effective when the seeds or propagules of key species are present; however, natural regeneration requires as much as 20 years [107]. By modification of soil surface (ground roughening, creation of microcatchments), reseeding in degraded lands, choosing the correct timing for seeding, improving the organic content of the soil and efficient management of herbivores, it may be possible to accelerate the restoration process [108–112].

Adequate precautions are needed while rehabilitating the degraded ecosystems because exotic species may not adapt to the harsh environment and may require large amounts of water leading to irrigation-related problems such as water logging and soil salinization. When these exotic species become naturalized, there is greater danger of them assuming dominance over the native vegetation.

Overgrazing is perceived as the major cause of desertification and loss of vegetation in Kuwait [113, 114], but other factors such as the nature of the substrate, soil compaction, rainfall characteristics, buildup of the seed bank in the soil and vegetative regeneration potential have considerable consequences for plant restoration. Without the influence of grazing, the positive impact of rainfall depends on soil conditions, with deep sandy soil producing the best results [115]. According to [116], the rain-use-efficiency (amount of biomass/mm of rainfall received during the growing season per unit area) may be reduced from 4 to 5 kg dry matter per ha per mm on deep sandy soil to as low as 0.5–1.0 kg dry matter per ha per mm on shallow soils. Under conditions prevalent in Kuwait also, deep sandy and loamy sand substrates favor good plant growth, particularly of *Rhanterium epapposum*, because they allow deep percolation of rainwater. The surface layer after drying acts as insulation against evaporation from subsurface layers. This increases the amount of water available in the root zone. However, the sandy soil is effective in retaining moisture and promoting plant growth only when the surface soil layer is not lost through wind or water erosion. Le Houerou [116] also reported better vegetation recovery in sandy soils than in compacted soils. In contrast, compact layers (formation of soil crust or compacted by off-road traffic) favor greater surface runoff and this, apart from removing whatever little thin film of loose soil may remain, washes away seeds that are deposited on the surface. Regeneration is greatly improved by creating sandy depressions.

A number of studies conducted at KISR have confirmed that long-term drought can alter vegetation as dramatically as overgrazing [113, 117]. This contradicts the commonly held view that cessation of grazing and deleterious human activities will improve range conditions significantly [117]. Rainfall distribution is also critical for vegetation recovery. *Rhanterium* seed germination takes place only during years with individual rain events in excess of about 30 mm [59]. Therefore, under arid conditions, supplemental irrigation improves seed germination, seedling establishment and plant cover when rainfall is either inadequate or distributed unevenly [45, 60]. In contrast, new shoots are produced from the underground shoots after the receipt of moderate precipitation, although further plant development and biomass production are dependent on the total and even distribution of rainfall and protection from grazing.

Seed germination in *Rhanterium* under field conditions is very low (1–2%) and varies considerably from one lot to another. Recent KISR studies have shown that germination of *Rhanterium* seeds can be increased from 1 to 34% by prechilling the seeds for 90 d at 4°C and then germinating at 18°C [65]. Therefore, it is desirable to germinate the seeds in the laboratory, and then to transplant the hardened seedlings into the desert during the favorable season (winter).

Some native plants such as *Rhanterium epapposum* have an excellent potential for vegetative regeneration from subterranean stumps. Stumps in heavily grazed, sandy areas can still produce new shoots every year to prevent the shrub from drying completely. Protecting the site from grazing can greatly enhance vegetative regeneration in a short period of time [58, 66].

Based on studies conducted at KISR, the following strategy has been suggested to restore the deteriorated plant community [14, 45, 60]:

1. Reduce or eliminate the causes of degradation (off-road traffic, pollution, etc.).
2. Initiate soil-improving processes (reduce soil erosion, improve soil organic matter, nutrient status).
3. Undertake measures to improve microsite water availability and nutrient cycling (reduce runoff, improve soil infiltration capacity by pitting, ripping, terracing, establishing microcatchments).
4. Reduce detrimental ecosystem interactions while increasing synergies among ecosystem components (establish key species and ameliorate micro-environmental conditions, reducing inter species competition, integrating soil, vegetation and landscape level strategies).

The above strategy will require the establishment of protected areas, adoption of efficient propagation and growing techniques and undertaking revegetation programs using the latest soil and water conservation techniques.

4.6 Establishment of Protected Areas for Rehabilitation of Native Ecosystems

Although subterranean stumps manage to produce sufficient quantities of new shoots every year, intensive grazing prevents them from flowering and seed production. Therefore, protection from grazing by the establishment of enclosures would allow plants to recover sufficiently, in order to flower and set seed. Protected areas could provide a genetic source for future large-scale restoration projects. KISR has successfully demonstrated complete recovery of the *Rhanterium* community to its pristine state by protecting the area from grazing and detrimental human activities [117].

In 1997, an exclosure was established in Sabriya oil field by fencing an area of approximately 20 km^2 to restrict access to the area and stop all detrimental activities. Before the exclosure was created, perennial woody shrubs were almost absent or overgrazed in the area. After 4 years of protection (1997–2001), the recovery of perennial shrub vegetation, especially *Rhanterium epapposum* was remarkable, with cover values for both shrubs and annuals closely comparable to that at the Sulaibiya Experimental Station (SES) [66]. However, most of the new *Rhanterium* plants in this exclosure were from underground woody stumps and no new seedlings appeared during the 4 years of protection, as compared to 252 new seedlings recorded in the 10 quadrats (area of each quadrat being 0.25 m^2) at the SES.

These exclosures also provide opportunities for long-term monitoring of ecosystem health. Nevertheless, they should not be considered as sole techniques/tools for rangeland improvement or restoration of degraded ecosystems.

4.7 Rehabilitation and Ecosystem Monitoring

During 2000–2006, KISR undertook a number of pilot revegetation studies in areas impacted by oil contamination, military activities, detonation of ammunitions in large underground pits and off-road traffic movement. Hardened seedlings of naturalized species and seed mixes containing various native species were used to restore native plant communities of the area. Protective irrigation was given to improve seed germination and seedling establishment. The success of the revegetation program was assessed by undertaking a vegetation survey in revegetated, nonrevegetated areas and undisturbed (e.g. SES) areas. These revegetation programs were very useful in improving species richness, biomass production and facilitating recovery of native species such as *Rhanterium epapposum* [45, 60].

KISR also successfully used the bioremediated soil in natural landscape settings to grow a number of ornamental and fodder plants [118]. Although the results were encouraging, further investigations are required to assess the impact of uptake of petroleum hydrocarbons on the environment and their ultimate use.

In recognizing the urgent need for addressing the oil contamination and restoration of degraded ecosystems to minimize their detrimental effects on the environment and well being of the people, the United Nations Compensation Committee (UNCC) has approved Kuwait's claims for remediation of damage to terrestrial resources (claim # 5000450) and for remediation of areas damaged by oil lakes, oil contaminated piles, oil trenches and oil spills (claim # 5000454). The above claims, namely "Remediation of damaged terrestrial resources" and "Remediation of areas damaged by tarcrete," designated as Kuwait Environmental Remediation Program (KERP), deal with the establishment of 70 "Resource Islands" (420 km^2) and revegetation of 30 km^2 of tarcrete-affected areas. The Kuwait National Focal Point (formerly known as Public Authority for Assessment of Compensation for Damages Arising from Iraqi Aggression) is taking steps to rehabilitate the environmental damage in accordance with the UNCC's decisions. It involves rehabilitation of damage to terrestrial, groundwater and marine and coastal areas. Currently, KNFP is preparing a comprehensive rehabilitation plan, which will be implemented in the near future. The success of the KERP depends largely on the restoration of native species in the damaged areas as they have the greatest chances for survival, establishment and growth under the prevailing environmental conditions. However, because of low productivity and harsh weather conditions, the natural recovery of native plants in such heavily impacted areas usually requires decades, rather than a few years.

5 Conclusions

Military activities during the occupation and subsequent liberation war caused direct and indirect damage to Kuwait's environment and ecosystems. Direct damage to the environment and ecological components of the Kuwaiti desert include the following. Damage due to military operations including troop transport over the fragile desert surface. Construction of ground fortifications, placement of thousands of mines in the desert and marine surface, construction of oil trenches filled with crude oil, air and ground operations during the liberation war, and the release of huge quantities of oil into Kuwait's water. Additionally, torching and damage of operational oil wells and post-war activities to put out the oil-fires, demining operations and disposal of unused ammunition caused further direct damage. All these activities impacted the environment, soil, native vegetation, and other natural resources. Some causes of indirect damage include the effects of secondary pollutant products or weathered materials from oil on the environment and ecosystem; salinization of desert soil from the seawater used in fire fighting, alteration of physical and chemical properties of soil due to oil contamination; and disintegration and dispersal of oil-contaminated soil in dust storms. Several studies have been conducted by local and international organizations to understand the nature and extent of the damage to the environment and ecosystem. The results clearly indicate that the problems persist even after 15 years. In fact, although the lakes and lagoons that contained oil have been drained and many of them have dried out, their hazard potential has actually increased. Much of the terrestrial rehabilitation work is yet to be undertaken and is summarized below:

- Long-term impacts of soil compaction and heavy oil contamination must be studied so that an appropriate rehabilitation approach can be adopted.
- Investigate any possible alteration in soil microbial ecology due to oil contamination.
- Monitoring of the lasting effects of oil release, the tarcrete, open-burning and detonated mines and ordinances on desert environment and ecosystem components.
- Adopt an action plan for large-scale rehabilitation of heavily contaminated soil and restoration of degraded rangelands considering UNCC recommendations.
- Monitor long-term impact of seepage of oil into groundwater aquifers.

- Monitoring of effectiveness of rehabilitation measures on specific types of damage.
- Assess long-term impact of the war on public health and biodiversity.

References

1. Omar SAS, Briskey E, Misak R, Asem ASO (2000) The Gulf War impact on the terrestrial environment of Kuwait: an overview. In: Austin JE, Bruch CE (eds) The environmental consequences of war: legal, economic and scientific perspectives. Cambridge University Press, Cambridge, pp 316–337
2. Omar SAS, Misak R, Bhat NR, Shahid SA, Delima EC (2003) Assessing damage magnitude and recovery of the terrestrial ecosystem/Follow up of natural and induced recovery. Kuwait Institute for Scientific Research Report No. KISR 7105, Kuwait
3. Annual Statistical Report (2006) Ministry of planning. Statistics and Information Sector, Kuwait
4. Salam AM, Al-Mazrooei S (2007) Changing patterns of climate in Kuwait. Asian J Water, Environ Pollut 4:119–124
5. Middleton N, Thomas D (1997) World atlas of desertification. United Nations Environment Program/Arnold, p 182
6. Le Houerou HN (1992) An overview of vegetation and land degradation in world arid lands. In: Dregne HE (ed) Degradation and restoration of arid lands. Texas Tech University, Lubbock, TX, pp 127–163
7. Roy W, Omar SAS (2005) Application of GIS in soil classification and land use planning for the State of Kuwait. http://WWW.Kfupm.edu.sa
8. KISR (1999) Soil survey of for the State of Kuwait. Volume II. Reconnaissance survey AACM Int., Adelaide, Australia, p 270
9. Omar SASS (2007) Vegetation of Kuwait Kuwait Institute for Scientific Research, Kuwait, p 161
10. Omar SA, Misak R, King P, Shahid S, Abo-Rizq H, Grealish G, Roy W (2001b) Mapping the vegetation of Kuwait through reconnaissance soil survey. J Arid Environ 48:341–355
11. Omar SA, Misak R, Shahid SA, Malik R, Madouh T, Abo-Rezq H (2001a) Rehabilitation and management of Kuwait's rangelands for sustainable yield. Report No. KISR 6087. Kuwait Institute for Scientific Research, Kuwait
12. Al-Awadi J, Misak R (2000) Field measurement of Aeolian sand processes and sand control measures. Kuwait J Sci Eng 27:159–176
13. Omar SAS (1982) Baseline information on native plants of Kuwait. Kuwait Institute for scientific research technical report no. KISR 1790, Kuwait
14. Omar SAS, Bhat NR (2008) Alteration of the Rhanterium epapposum plant community in Kuwait and restoration measures. Int J Environ Studies 65:139–155
15. United Nations Compensation Commission (UNCC) (2004) Claim of the State of Kuwait. Claim No. 5000454. United Nations Compensation Commission, Report No. S/AC26/2004/17
16. Al-Hassan JH (1992) Iraqi invasion of Kuwait: An environmental catastrophe. Fahad Al-Marzouk Publishers, Kuwait
17. Al-Awadhi NM, Williamson KJ, Isok JD (1993) Remediation of Kuwait's oil-contaminated soils. In: Kotecherski P, Calabrese EJ (eds) Hydrocarbon contaminated soils and groundwater. Lewis Publishers, Michigan, USA
18. Al-Awadhi N, Balba MT, Puskas K, Al-Daher R, Tsuji H, Chino H, Tsuji K, Iwabuchi M, Kumamoto S (1995) Remediation and rehabilitation of oil contaminated lake beds. J Arid Land Stud 58:195–198
19. Kwarteng AY (1998) Multitemporal remote sensing data analysis of Kuwait's oil lakes. Environ Int 24:121–137
20. Hussain T (1998) Terrestrial and atmospheric environment during and after the Gulf War. Environ Int 24:189–196

21. Johnson DW, Kilsby CG, McKenna DS, Saunders RW, Jenkins GJ, Smith FB, Foot JS (1991) Airborne observations of the physical and chemical characteristics of the Kuwait oil smoke plume. Nature 353:617–621
22. Hussain T (1995) Kuwaiti oil fires: regional environmental perspectives. Pergamon Press, Ltd., Oxford, UK
23. Omar SAS, Literathy P, Misak R, Grealish G, Briese E, Mukhopadhyaya A, Delima E, Bhat N (2002) Report on the UNCC visit to Kuwait: United Nations Compensation (UNCC) "F4" Environmental claims, Third Installment (Terrestrial, Ground Water and Buildings). Kuwait Institute for Scientific Research
24. Price ARG (1998) Impact of the 1991 Gulf War on the coastal environment and ecosystems: current status and future prospects. Environ Int 24:91–96
25. Al-Awadhi N, El-Nawawy A, Al-Daher R (1992) In situ and on-site remediation of oil contaminated soils in Kuwait. Proceedings of the Third World Academy of Sciences
26. Al-Awadhi N, Al-Daher R, El-Nawawy A (1993) Evaluation of in-situ enhanced land farming and on-site soil pile composting technologies. Proceedings of 11th Australian Biotechnology Conference, September 1993
27. Al-Awadhi N (1993). Remediation of Kuwait's desert. Petroleum energy center, Japan, Green Age 1:4–5.
28. Misak R, Omar S (2004) Military operations as major cause of soil degradation and sand encroachment in arid regions (The case of Kuwait). J Desert Stud 14:25–28
29. Sadiq M, McCain JC (1993) The Gulf War aftermath: an environmental tragedy. Kluwer, Boston, pp 59–108
30. Kwarteng AY, Al-Ajmi D (1996) Using Landsat Thematic data to detect and map vegetation changes in Kuwait. Int Arch Photogram Remote Sens 31:398–405
31. Kwarteng AY, Al-Ajmi D (1997) Satellite remote sensing applications in the State of Kuwait. Kuwait Institute for Scientific Research, Kuwait, pp 101
32. El-Din MNA, Dashti AH, Abdu AS, Nasrullah HA (1996) Environmental impact of burned oil wells and military operations on some desert plants and soils of Kuwait. Proceedings of International Conference on the Effects of the Iraqi Aggression on the State of Kuwait, vol 3. Environment and health effects and remediation Kuwait Univ., pp 167–186
33. Al-Sudairawi M, Misak R, Al-Nafeesi R (1996) Environmental impact assessment of the Iraqi strategic mine fields in the southern portion of Kuwait. Proceedings of the international conference on the effects of the Iraqi aggression on the State of Kuwait. vol 3. Environmental Health and Remediation, pp 249–266
34. Kwarteng AY, Chavez Jr PS (1998) Mapping and change detection study of Kuwait city and environs using multitemporal Landsat Thematic Mapper data. Int J Remote Sens 19:1651–1662.
35. Saeed T, Al-Hashash H, Al-Matrouk K (1998) Assessment of the changes in the chemical composition of the crude oil spilled in the Kuwait desert after weathering for five years. Environ Int 24:141–152
36. Gerges M (1993) On the impacts of the 1991 Gulf War on the environment of the region: general observations. Mare Pollut Bull 27:305–314
37. Bem H, Bou-Rabee F (2004) Environmental and health consequences of depleted uranium use in the 1991 Gulf War. Environ Int 30:123–134
38. Abdulraheem M (2000) War-related damage to the marine environment in the ROPME Sea Area. In: Austin JE, Bruch CE (eds) The environmental consequences of war: legal, economic and scientific perspectives. Cambridge University Press, Cambridge, UK
39. Zaman S, Alsdirawi F (1993) Assessment of Gulf environmental crisis: impacts on Kuwait's desert renewable natural resources. Report No. KISR 4247. Kuwait Institute for Scientific Research, Kuwait
40. Al-Houty W, Abdal M, Zaman S (1993) Preliminary assessment of the Gulf on Kuwaiti desert ecosystem. J Environ Sci Health 28(8):1705–1726
41. Ahmed MH, El-Raey M, Nasr SM, Frihy OE (1998) Socio-economic impact of pollution on ecosystems of the Arabian Gulf. Environ Int 24:229–237

42. Al-Ghadban NA, El-Sammak A (2005) Sources, distribution and composition of the suspended sediments, Kuwait Bay, Northern Arabian Gulf. J Arid Environ 60:647–661
43. Viswanathan MN (1995) Rainfall induced transport of crude oil contaminants from unsaturated zones. Kuwait Institute for Scientific Research Report No. KISR WH007K, Kuwait
44. Al-Attar MH (1994) An integrated approach for overcoming the adverse environmental impact inflicted upon Kuwait during the Iraqi occupation. Proceedings of international symposium on environment, Budapest, Hungary
45. Omar SA, Bhat NR, Shahid SA, Asem A (2006) Land and vegetation degradation in war-affected areas in the Sabah Al-Ahmad Nature Reserve of Kuwait. Eur J Sci Res 14:146–158
46. Taylor HM, Gardner HR (1963) Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. Soil Sci 96:153–156
47. Khalaf FI, Al-Ajmi D (1993) Aeolian processes and sand encroachment problems in Kuwait. Geomorphology 6:111–134
48. Koch M, Al-Baz F (1998) Identifying the effects of the Gulf War on the geomorphic features of Kuwait by remote sensing and GIS. Photogram Eng Remote Sens 64:739–747
49. United Nations Compensation Commission (UNCC) (2003) Claim of the State of Kuwait. Claim No. 5000450. United Nations Compensation Commission, Report No. S/AC26/2003/31
50. Al-Ajmi D, Misak R, Khalaf FI, Al-Sudairawi M, Al-Dousari AM (1994) Damage assessment of the desert and coastal environment in Kuwait by remote sensing. Report No. KISR 4405. Kuwait Institute for Scientific Research, Kuwait
51. Al-Ajmi D, Misak R, Al-Dousari A, Al-Enzi A (1996) Impact of Iraqi war machinery and ground fortifications on the surface sediments and Aeolian processes in Kuwait. Proceedings of the international conference on the effects of the Iraqi aggression on the State of Kuwait, vol 3. Environmental and Health Effects and Remediation. The Center of the Gulf and Arabian Peninsula Studies Kuwait.
52. Al-Dabi H, Koch M, El-Baz F, Al-Sarawi M (1998) Mapping and monitoring of sand dune patterns in Northwest Kuwait using Landsat TM images. In: Omar SAS, Misak R, Al-Ajmi D (eds) Sustainable development of arid zones: assessment and monitoring of desert ecosystems, vol 1. A. A. Balkema, Rotterdam, pp 273–279
53. El-Baz F, Al-Sarawi M (2000) Atlas of the Kuwait from satellite images. Kuwait Foundation for the Advancement of Sciences
54. Misak R, Omar S (2003) Environmental damages caused by Iraqi ground fortifications with emphasis on sand mobilization in Kuwait. Technical Paper for the Oral Proceedings on the Third Installment Environmental Damage Claims Kuwait Institute for Scientific Research
55. Al-Awadi J, Gemak J (1998) Sand traps for measurement of eolian sand drift rate. In: Omar SAS, Misak R, Al-Ajmi D (eds) Sustainable development of arid zones: assessment, vol 1, pp 177–188
56. Omar SA, Bartolome J, Al-Mahran Z (1996) Growth and nutritive variations in forage crops exposed to crude oil. Proceedings of the international conference on desert development in the Arab Gulf countries, Kuwait
57. Brown G, Schoknecht N (2001) Off-road vehicles and vegetation patterning in a degraded desert ecosystem in Kuwait. J Arid Environ 49:413–427
58. Brown G (2002a) Species richness, diversity and biomass production of desert annuals in an ungrazed Rhanteriun epapposum community over three growth seasons in Kuwait. Plant Ecol 165:53–68
59. Brown G (2002b) Community composition and population dynamics in response to artificial rainfall in an undisturbed desert annual community in Kuwait. Basic Appl Ecol 3:145–156
60. Omar SA, Bhat NR, Shahid SA, Asem 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
61. El-Sheikh MA, Abbadi GA (2004) Biodiversity of plant communities in the Jal Az-Zor National Park, Kuwait. Kuwait J Sci Eng 31:77–105

62. Alsdirawi F (1991) The negative impact of the Iraqi invasion on Kuwait's protected areas. Fourth World Congrss on National Parks and Protected Areas
63. Al-Hashem MA, Brain PF, Omar SA (2007) Effects of oil pollution at Kuwait's greater Al-Burgan oil field on polycyclic aromatic hydrocarbon concentrations in the tissues of desert lizards *Acanthodactylus scutellatus* and their ant prey. Ecotoxicology 16:551–555
64. Al-Hashem MA, Brain PF, Omar SA (2008) Effects of oil pollution at Kuwait's Greater Al-Burgan oil field on the timing of morning emergence, baking time and foraging behaviors by the sand lizard Acanthodactylus scutellatus. Pak J Biol Sci 11:589–594
65. Zaman S (2006) Establishment of seed bank unit for native plants of Kuwait. Report No. KISR 8536. Kuwait Institute for Scientific Research, Kuwait
66. Brown G, Al-Mazrooei S (2003). Vegetation regeneration in a seriously degraded *Rhanterium epapposum* community in Northern Kuwait after four years of protection. J Environ Manage 68:387–395
67. Johnson AW, Sallberg J (1960) Factors that influence field compaction of soils. Highway Research Board Bulletin 272, Department of Transportation, Washington DC, USA
68. Webb RH, Wilshire HG (1980) Recovery of soils and vegetation in a Mojave Desert ghost town, Nevada, U.S.A. J Arid Environ 3:291–303
69. Webb RH (2002) Recovery of severely compacted soils in the Mojave desert, California, USA. Arid Land Res Manage 16:291–305
70. Petroleum Economist (1992) The oil fires' story. 21–28 April 1992
71. Al-Ghunaim A (1997) Devastating oil wells as revealed by Iraqi documents. Center for Research and Studies of Kuwait, Kuwait
72. El-Baz F, Abuelgasim A, Koch M, Pax-Lenney M, Lambin E, Al-Dousari A, Marr P, Ryherd S, Morency R (1994) Detection by satellite images of environmental change due to the Gulf War. In: El-Baz F, Mukharita RM (eds) The Gulf War and the environment. Gordon and Breach Science, Lausanne, pp 1–24
73. Salam AJA (1996) The oil lake environment disaster. In: Al-Awadhi N, Balba MT, Kamizawa C (eds). Proceedings of the symposium on the restoration and rehabilitation of the desert environment. Elsevier, Amsterdam, pp 117–137
74. Hahn J (1991) Environmental effects of the Kuwaiti oil fires. Environ Sci Technol 25:1531–1532
75. Puskas K, Al-Awadhi N, Abdulla F (1995) Remediation of the oil contaminated sandy soil in a slurry reactor. Environ Int 21:413–421
76. Kwarteng AY (1999) Remote sensing assessment of oil lakes and oil polluted surfaces at the Greater Burgan oil field, Kuwait. Int J Appl Earth Obs Geoinf 1:36–47
77. Saeed T, Al-Bloushi A, Al-Matrouk K (1993) Assessment of the changes in the chemical components of the crude oil spilled in the Kuwait desert after weathering for five years. Environ Int 24:141–152
78. Al-Sulaimi J, Viswanathan MN, Székely F (1992) Effect of oil pollution on fresh groundwater in Kuwait. Environ Geol 22:246–256
79. Al-Awadi E, Quinn M, Mukhopadhyaya A, Houser A, Akber A, Al-Haddad A, Al-Rahedi M (2008) Extent and nature of hydrocarbon occurrence in the groundwater of Kuwait. Environ GeolStill under printing (in press)
80. Sheppard CRC, Price AR, Robert CM (1992) Marine ecology of the Arabian region: Patterns and processes in extreme tropical environments. Academic Press, London
81. Price ARG (1993) The Gulf: Human impacts and management initiatives. Mar Pollut Bull 27:17–27
82. Readman JW, Fowler SW, Villeneuve JP, Cattini C, Oregioni B, Mee LD (1992) Oil and combustion-products contamination of the Gulf marine environment following the war. Nature 358:662–664
83. Bu-Olayan AH, Subramanyam MNV, Al-Sarawi M, Thomas BV (1998) Effects of the Gulf War oil spill in relation to trace metals in water, particulate matter, and PAHs from the Kuwaiti coast. Environ Int 24:789–797

84. ROPME/NOAA/IOC. 1992. 100-day oceanographic cruise, Feb. 1992 – June 1992. Kuwait: Regional Organization for the Protection of the Marine Environment, p 14
85. Fowler SW (1985) Coastal baseline studies pollutants in Bahrain, UAE and Oman. JAEA paper for Regional Symposium for the Evaluation of Marine Monitoring and Research Programs. Dec. 8–12, 1985. Al-Ain University, UAE
86. International Union for Conservation of Nature and natural Resources (IUCN) (1987) Saudi Arabia: An assessment of biotypes and management requirements for the Arabian Gulf Coast. MEPA Coastal and Marine Management Series Report No. 5,York, Y01 5DD, UK: IUCN
87. Linden O, Abdulraheem MY, Gerges MA, Alam I, Behbehani M, Borhan MA, Al-Khassab IF (1990) State of the marine environment of the ROPME Sea Area. UNEP Regional Seas Reports and Studies, No. 112, Rev. 1. UNEP, Nairobi
88. World Meteorological y Organization (WMO) (1991) Global atmospheric watch No. 72. Report of the WMO meeting of experts on the atmospheric part of the Joint UN response to the Kuwait oil field fires. Geneva, April 17–30, 1991
89. Price ARG, Robinson JH. (1993) (eds) The Gulf War: coastal and marine environmental consequences. Mar Pollut Bull 27:1–380
90. Price ARG (1988) Characteristics and assessment of critical and other marine habitats in the ROPME Sea Area and Res Sea. Proceedings ROPME workshops on the coastal area development. UNEP Regional Seas Report and Studies No. 90: 57–71. Nairobi, Kenya, UNEP
91. Literathy P (1993) Considerations for the assessment of the environmental consequences of the 1991 Gulf War. Mar Pollut Bull 27:349–365
92. McGlade JM, Price ARG (1993) Multidisciplinary modeling: An overview and practical implications for the governance of the Gulf region. Mar Pollut Bull 27:361–375
93. Jones DA, Watt I, Plaza J, Woodhouse TD, Al-Sanei M (1996) Natural recovery of the intertidal biota within the Jubail Marine Wildlife Sanctuary after the 1991 Gulf War oil spill. In: Krupp F, Abuznada FH, Nader IA (eds). A marine wildlife sanctuary for the Arabian Gulf: environmental research and conservation following the 1991 Gulf War oil spill. Senckenbergische Naturforschende Gesellschaft and National Commission for Wildlife Conservation and Development, Frankfurt, Germany and Riyadh, Saudi Arabia, pp 138–158
94. Downing N (1991) A survey of the coral island of Kubbar, Qaru, and Umm. Al-Maradem, Kuwait. Report to the IUCN, York Y01, 5DD, UK. International Union for the Conservation of Nature and Natural Resources, pp 1–22
95. Readman JW, Bartocci J, Tolosa I, Fowler SW, Oregioni B, Abdulraheem MY (1996) Discrete bands of petroleum hydrocarbons and molecular organic markers identified within massive coral skeletons. Mar Pollut Bull 32:437–443
96. Dobson MC, Kwarteng AY, Ulaby FT (1997) Use of SIR-C/X-SAR to monitor environmental damages of the 1991 Gulf War in Kuwait. Geosci Remote Sens 1:119–121
97. Literathy P, Quinn M (2006) Monitoring of Petroleum-related environmental contamination using fluorescence fingerprinting. Water Pract Technol Vol 1 & 2 @IWA Publishing 2006 doi: 10.2166/WPT.2006029.
98. Literathy P, Quinn M, Al-Rashed M (2003) Pollution potential of oil-contaminated soil on ground water resources in Kuwait. Water Sci Technol 47:259–265
99. Saif UD, Al-Dousari A, Literathy P (2008) Evidence of hydrocarbon contamination from the Burgan oil field, Kuwait – Interpretations from thermal remote sensing data. J Environ Manage 86:605–615
100. McGlade JM, Pauly D, Silvestre G (1996) Interdisciplinary scientific methodologies for the sustainable use and management of coastal resources systems. Final Report to CEC (Contract CTI*CT93-0349) Brussels CEC
101. Kuwait Oil Company (1993) Physical damage to the desert surface. Kuwait Oil Company Claim No. 3. Consultant's Report
102. Misak R, Omar S (2007) Environmental damages from minefields. J Mine Action 11(2): 1–5
103. Balba MT (1994) Remediation and rehabilitation of the Jaidan garden. Proposal to Kuwait Institute for Scientific Research

104. Balba MT, Al-Daher R, Al-Awadhi N, Chino H, Tsuji H (1998) Bioremediation of oil-contaminated desert soil: The Kuwaiti Experience. Environ Int 24:163–173
105. Al-Awadhi N, Puskas K, Al-Daher R, El-Naway A, Literathy P (1996) To what extent can nature remediate the oil contamination in Kuwait soils? Proceedings of the international conference on the effects of the Iraqi aggression on the State of Kuwait, vol 3. Environmental and Health Effects and Remediation, pp 331–355
106. Le Houerou HN (2000) Restoration and rehabilitation of arid and semiarid Mediterranean ecosystems in North Africa and West Africa: A review. Arid Soil Res Rehabilit 14:3–14
107. Thalen DCP (1979) Ecology and utilization of desert shrub rangelands in Iraq. Junk, The Hague, The Netherlands, p 448
108. Schuster JL (1998) Restoring structure and function of degraded rangeland ecosystems. In: Omar SAS, Misak R, Al-Ajmi D, Al-Awadhi N (eds) Sustainable development in arid zones, vol 2. Management and improvement of desert ecosystems. Balkema, Rotterdam, pp 373–382
109. Brown G (2001) Vegetation ecology and biodiversity of degraded desert areas in north-eastern Arabia. Habilitation thesis. Rostock University
110. Brown G (2003) Factors maintaining plant diversity in degraded areas of northern Kuwait. J Arid Environ 54:183–194
111. Baskin CC, Baskin JM (1998) Seeds, ecology, biogeography and evolution of dormancy and germination. Academic Press, San Diego
112. Gutterman Y (1997) Spring and summer daily subsurface temperatures in three microhabitats in a flat natural loess area in the Negev desert, Israel. J Arid Environ 36:225–235
113. Zaman S (1997) Effects of rainfall and grazing on vegetation yield and cover of two arid rangelands of Kuwait. Environ Conserv 24:344–350
114. Misak R, Al-Awadi JM, Omar SAS, Shahid SA (2002) Soil degradation in Kabd area, south-western Kuwait City. Land Degrad Develop 13:403–415
115. Li XR, Zhang ZS, Zhang JG, Wang XP, Jia XH (2004) Association between vegetation pattern and soil properties in the south-eastern Tennger Desert, China. Aridland Res Manage 18:369–383
116. Le Houerou HN (1986) The deserts and arid zones of Northern Africa. In: Evanari M, Noy-Meir I, Goodall DW (eds) Ecosystems of the world 12B. Hot Deserts and Arid Shrublands. B. Elsevier, The Netherlands, Amsterdam, pp 101–147
117. Omar SAS (1991) Dynamics of range plants following 10 years of protection in arid rangeland in Kuwait. J Arid Environ 21:99–111
118. Al-Zelzelah H, Grina R, Bhat NR, Shahid SA, Suleiman MK (2001) Assessment and suitability of bioremediated soils for greenery landscape planting: The Ahmadi bioremediated soil park. Final Report No. KISR 6598, Kuwait
119. Public Authority for Assessment of Compensation for Damages Arising from Iraqi Aggression (1997) Environmental damage claims prioritization report. May 1997
120. Ministry of Defense (1993) Ammunition and explosives disposal report. State of Kuwait, Kuwait
121. El-Baz F, Mukharita R (1994) The Gulf War and the environment. Gordon and Breach Science Publishers, Lausanne