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LAND DEGRADATION INDICATORS IN KUWAIT

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ABSTRACT

In arid regions, such as Kuwait, land degradation is exacerbated by the scarcity of rainfall and intensive wind and water erosion. In Kuwait seven land degradation indicators were recognized and described. These are: soil erosion by wind and/or water; deterioration of vegetation cover; soil crusting and sealing; soil compaction; soil contamination by oil; and soil salinization. Four areas in Kuwait, namely Al Mutlaa, Ras Al-Sabiyah, Sulaibiyah and Ahmadi-Al-Dahr, were studied to assess the extent and magnitude of land degradation. Remote sensing images and the following parameters were investigated in each area: vegetation cover; soil bulk density; infiltration capacity; and top soil resistance. The areas showed significant variations in vegetation cover, and increase in erosion by wind and water and soil compaction. Based on the percentage of vegetation cover and the physical properties of the soil, three classes of land degradation are identified. These classes are: severe; moderate; and slight. Overgrazing was shown as a main cause of land degradation, followed by military operations, quarrying and camping. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS: degradation; vegetation; erosion; soil compaction; oil pollution; salinization; Kuwait

INTRODUCTION

In Kuwait, the scarcity and irregularity of rainfall, the availability of sand supply areas and the prevalence of strong NW winds significantly influence the stability and productivity of the desert ecosystem. Geographically, the State of Kuwait is situated at the northwestern corner of the Arabian Gulf and it covers an area of about 17 818 km^2. Kuwait is located on the downwind side of the high deflational area of the Mesopotamian flood plain in southern Iraq. During summer, the prevailing northwesterly wind, which reaches a maximum of 29 $m\,s^{-1}$ in June, transport sands and finer particles from this flood plain towards Kuwait (Al-Awadhi and Misak, 2000). Climatically, like most parts of the Arabian Peninsula, a desert-type environment with scanty rainfall and hot dry weather characterizes the climate of Kuwait. Summer is very hot, especially in July and August, with mean temperatures of 37·4°C and maximum mean temperatures of 45°C (Al-Sudairawi *et al*., 1999). The seasonal rainfall varies from 28 (1963–1964) to 260 mm (1975–1976), and the average yearly total rainfall is approximately 115 mm, with an evaporation rate of 16·6 $mm\,d^{-1}$.

In more than a decade the vulnerable terrestrial environment of Kuwait has been subjected to intensive pressure from urbanization, over utilization of resources and war activities. Seven indicators of land degradation have been recognized in Kuwait.

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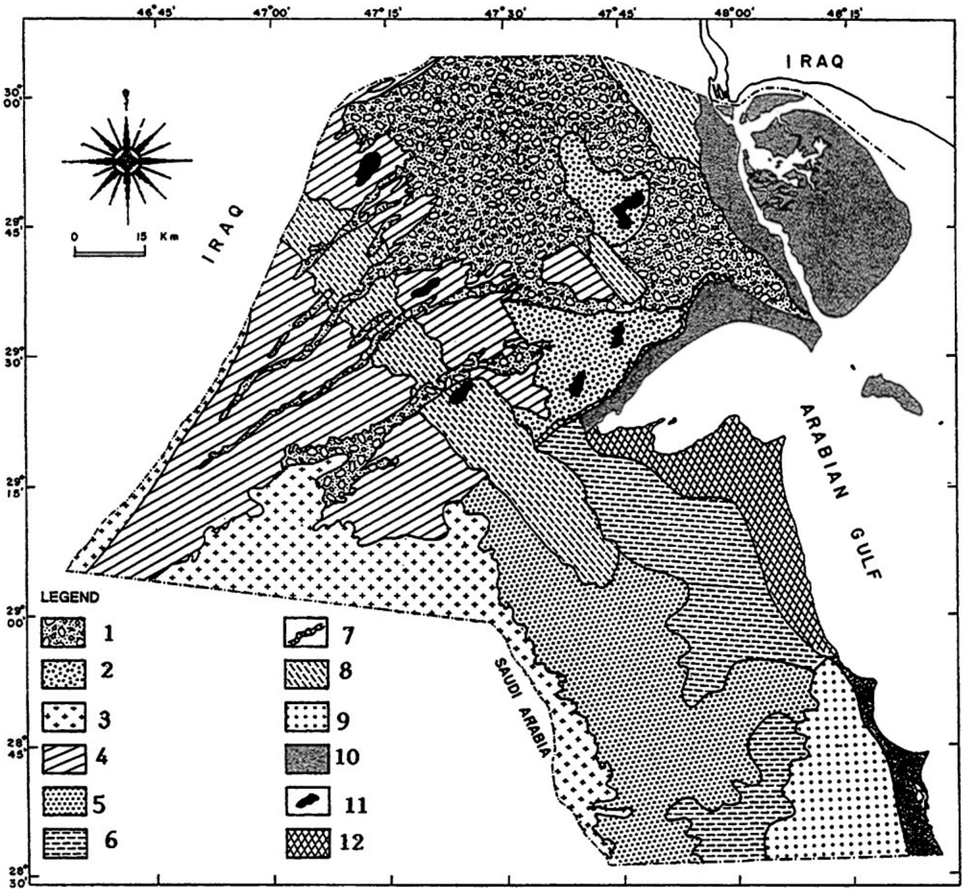

Figure 1. Surface sediment map of Kuwait (1990). 1 = Gravel lag, 2 = Desert floor deposits covered by siliclastic granule lag, 3 = Desert floor deposits covered by pebbly and granular lag rich in calcretic debris, 4 = Deflated rugged sand sheets, 5 = Active sand sheets, 6 = Smooth sand sheets, 7 = Fall dunes, 8 = Barchan dunes, 9 = Barchanoid ridges, 10 = Coastal plain deposits, 11 = Playa deposits, 12 = Urban areas (after Khalaf and Al-Ajmi, 1993).

Soil Erosion by Wind

The sand areas in Kuwait are categorized into two major groups: (1) active sand sheets and sand dune fields (highly mobile sand bed), which have surface sand accumulations composed of unprotected well-sorted mobile sand; and (2) smooth sand sheets and rugged vegetated sand sheets (lesser mobility), which are made up of a mix of mobile sand and non-erodible surface elements. Figure 1 shows the types of surface sediments lying over Kuwait's desert. The surface sediment particles of Kuwait are dominant in the size range that is predominantly susceptible to saltation movement (63–500 μm). This followed to a lesser extent by creep (>500 μm) and even less by suspension movement (<63 μm) (Khalaf *et al*., 1984). Sandstorms are very frequent in summer especially when the wind speed exceeds $6\,m\,s^{-1}$, The annual amount of sand drift is measured at about $7{\cdot}8 \times 10^4\,kg\,m^{-1}$ width (Al-Awadhi and Misak, 2000).

Soil Erosion by Water

The average annual rainfall in Kuwait is 115 mm (1975–2000) and rarely exceeds 200 mm, while the average annual total potential evaporation is about 6073 mm, corresponding to a potential evaporation rate of $16{\cdot}6\,mm\,d^{-1}$ (Kuwait International Airport). In spite of this, Kuwait experiences high intensity rainfall, usually in excess of

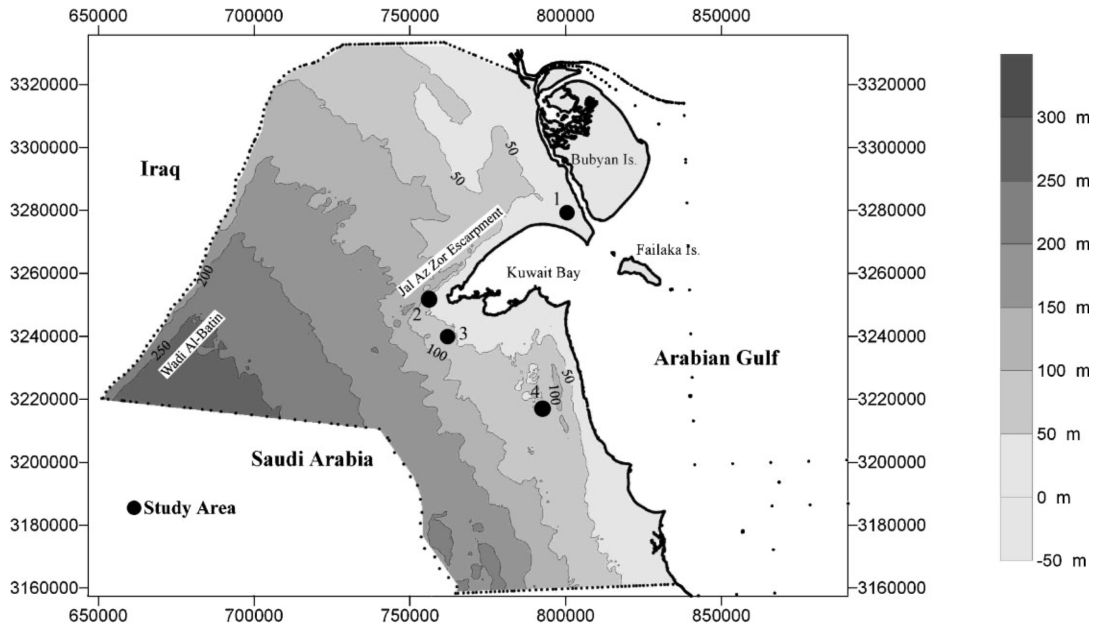

Figure 2. Topographic map of Kuwait, contour interval 50 m, and the locations of the study areas: (1) Ras Al-Sabiyah, (2) Mutlaa, (3) Sulaibiyah, and (4) Ahmadi-Al-Daher.

20 mm d^{-1} during the wet season from October to March. High-intensity rainfall in excess of the infiltration capacity falls over surface depressions resulting in surface runoff. Water erosion by runoff in Kuwait takes place on the slopes of the watershed in Jal Az Zor escarpment (Mutlaa area), Al-Ahmadi-Al-Dahar area and wadi Al-Batin (>265 m above sea-level) (Figure 2).

Based on field measurements in a main watershed area after the heavy rains of October 1997, Misak *et al.*, 2001 identified three degrees of water erosion in Kuwait, namely strong, moderate and slight. These degrees are differentiated by the depth of gullies and rills, e.g. strong water erosion creates gullies exceeding 150 cm in depth and rills of less than 20 m inter-spacing; moderate erosion creates gullies ranging in depth from 50 to 150 cm and rills of 20 to 50 m inter-spacing; and slight erosion creates gullies of less than 50 cm in depth and rills of more than 50 m inter-spacing. The degrees are not equivalent to international standards, but are based on local criteria in a relative sense. Accelerated water runoff in Kuwait usually prevails in areas where natural drainages in the wadis are degraded by grazing and human activities (Figure 3).

Deterioration of Vegetation Cover

In general, Kuwait's rangelands are characterized by an open scrub of small perennial shrubs, drought-resistant grasses and annual forbs that provide sources of livestock feed. Grazing is the dominant land-use type, representing 72·3 per cent of total land use (Omar *et al.*, 2001a). Some prime factors of vegetation deterioration are overgrazing, uprooting of woody shrubs and soil crusting or removal by heavy machinery and spring camping. Misak *et al.* (2001) showed that thousands of grazing animals and other human activities are concentrated around watering points, which are sporadically distributed throughout the desert. The degradation extended over time from the water points onto other adjacent areas causing severe rangeland degradation, soil trampling and compaction due to overstocking around these points. Livestock surveys also indicated that the number of grazing animals in the rangelands of Kuwait exceeded its productive capacity (Omar *et al.*, 2001b).

Figure 3. Paleodrainage pattern map of Kuwait (after Kwarteng *et al.*, 2000), mapped from aerial photographs in spring of a wet year of 2000. Degraded drainage patterns in the northwest–southeast trend are due to concealment of the main drainage basins along this trend underneath encroaching sand.

Soil Compaction, Crusting and Sealing

Compaction, sealing and crusting of soil surfaces are significant forms of in-situ soil degradation in Kuwait's desert ecosystem. They are mostly detected in degraded rangelands, particularly in the southern parts of Kuwait. The most common causes of soil compaction include trampling by livestock and off-road vehicle use on soils with low structural stability. At least 65 per cent of Kuwaiti soils are affected by some degree of compaction. Soil compaction inhibits the infiltration capacity of soils by 40–100 per cent and increases the bulk density of soils up to 50 per cent in comparison with uncompacted soils (Misak *et al.*, 2001). The thickness of soil crusts is observed to vary from a few centimetres to 40 cm. Consequently, surface runoff, water erosion, natural vegetation deterioration and sand drift become frequent all over the Kuwaiti desert.

Salinization

High evaporation and the occurrence of dry sandy soils in Kuwait effectively result in the leaching of the salts originally present in the soil profile. Salinity occurs in most of the areas that are classified under the order of Aridisols (Shahid *et al.*, 1999). According to a soil survey study (KISR, 1999), there are 785 000 ha of land with soils potentially suitable for irrigation development in Kuwait; currently only 23 000 ha of these soils are being used for agriculture. Irrigation with brackish water can further compound the problem of salinity.

Soil Oil Pollution

Prior to the liberation of Kuwait in February 1991, the Iraqi forces caused a huge catastrophe by destroying 1321 oil wells in different oil fields in Kuwait. The oil wells were burning approximately 4–6 million barrels of crude oil daily (Al-Besharah, 1992). This led to a tremendous destruction of the terrestrial environment, especially in the oil fields and adjacent areas. This damage was easily noticed from satellite images 'TM and SPOT®', aerial photographs, and field studies (e.g. Kwarteng and Bader, 1993; Kwarteng, 1998; Omar *et al*., 2000; Kwarteng *et al*., 1999; Omar *et al*., 2001c; Omar *et al*., 2002). Recently, in Kuwait three types of terrestrial oil pollution have been described, as follows:

(1) *Oil lakes*. These are accumulations of spilled crude oil from damaged well-heads and pipelines in topographically low lying areas within the oil fields. Currently, they are differentiated into wet and dry oil lakes (Kwarteng, 1998, Omar *et al*., 2000).
(2) *Tarcrete*. This consists of oil mist (oil rain) and oil soot and occurs within the upper layers of the soil as a 2–8 mm layer of unconsolidated soil. The soil contaminated by tarcrete is estimated to be in order of 6 per cent of the Kuwait total area (Kwarteng, 1998).

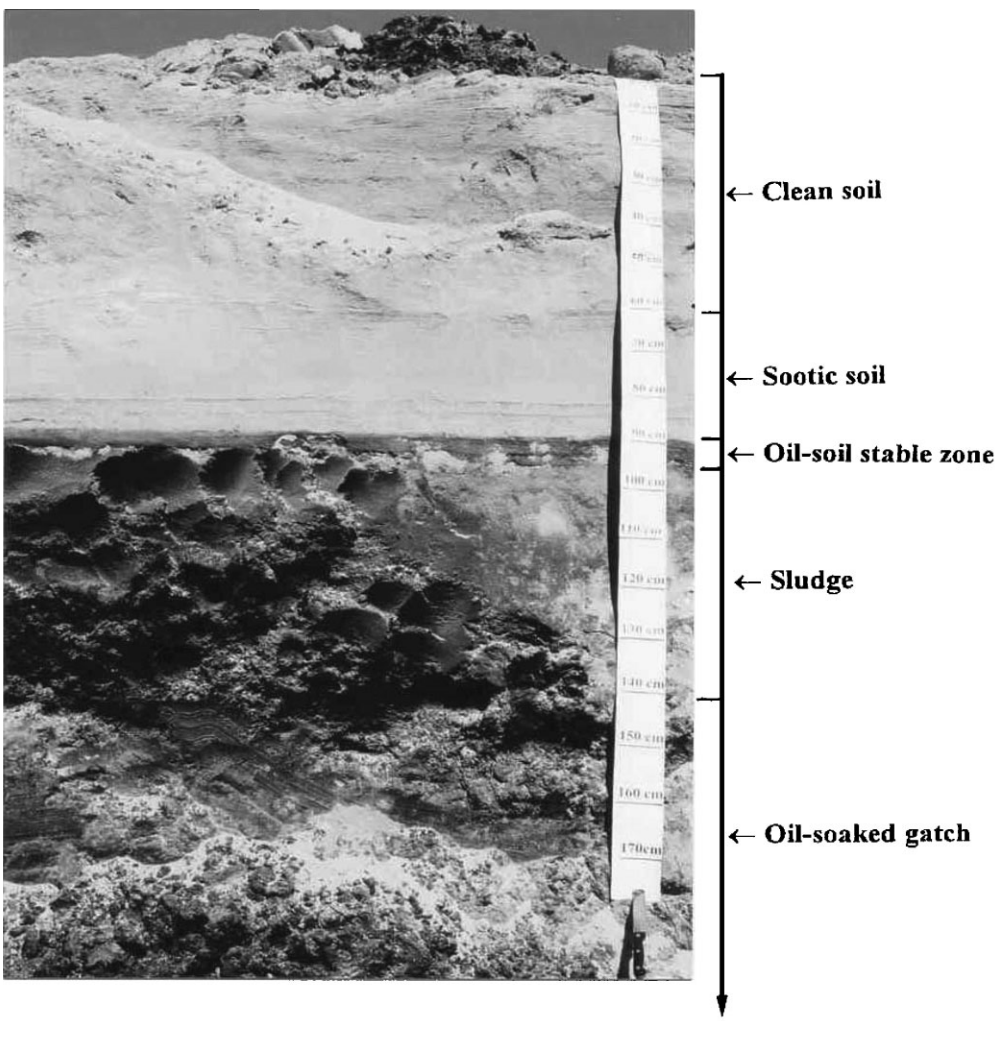

Figure 4. Oil trench in the north part of Kuwait (1999) showing different levels and depths of oil contamination.

(3) *Oil trenches*. They were a part of the strategic obstacle systems constructed by the Iraqi forces over a distance totalling 220 km. They are separate trenches filled with oil, which are 4–5 m wide and 2–3 m deep and extend along the southern border zone of Kuwait, 10–14 km from the Saudi Arabian border (Al-Ajmi *et al.*,1997). Omar *et al.* (2001c) studied another set of trenches along the northern coastal plain. The level and extent of oil contamination in oil trenches varies from place to place depending on the soil types and depth of oil penetration (Figure 4).

The objectives of this paper are to present an overview of land degradation processes and to investigate the extent and magnitude of degradation in four selected areas in the desert of Kuwait as well as to define the causes of land degradation.

METHODOLOGY

Four areas, namely Mutlaa, Sulaibiyah, Ras Al-Sabiyah and Ahmadi-Al-Daher, were selected for assessment of soil and vegetation degradation in protected and open sites (see Figure 2). The four areas were selected to present sites of different land uses (grazing, quarrying, camping, agricultural and animal production) and ecosystems (desert, coastal and transitional). Table I summarizes the field information of the investigated areas. Degradation assessments in each area were carried out at open and protected sites, i.e. non-fenced sites where grazing can be practiced and fenced sites, respectively. All selected protected sites were within close distance to the open sites. The following parameters were assessed.

Vegetation Cover

The vegetation cover was assessed by using 1 m^2 quadrats, that were randomly placed in each site. In each selected site a total of 15 quadrats were studied by estimating the total coverage as the percentage of litter/humus (dead plant material, which is valuable for grazing, stabilizing soil and adding nutrients to soil), total vegetative cover (annual and perennial species) and gravel. Dividing the quadrats into small portions and depending on a visual inspection by an expert, the coverage parameters were determined. Species of vegetation and density were also identified in each quadrat.

Top Soil Penetration

The top soil strength was measured randomly using a hand penetrometer. In each site, at least 10 penetration tests were conducted in compacted soils (i.e. on road tracks), and non-compacted soils (i.e. undisturbed soils) under similar conditions, and the average value was determined.

Bulk Density

For bulk density measurements a core method was used (USDA, 1996) and the porosity was calculated. A cylindrical metal sampler (100 mm in diameter, 130 mm in height, and with a 1020·5 cm^3 volume) was used. The

Table I. Main characteristics of the study areas

Study area	Major land use	Surface sediment	Area (km^2)	Ground elevation (m)
Ras Al-Sabiyah	Grazing and quarrying	Sand, pebbles, lagoon, silt	16	4–30
Mutlaa	Grazing and recreation; i.e. camping, military area, quarrying and animal farming	Gravel, pebbles calcrete, drift sand	33	50–150
Sulaibiyah	Agriculture, animal production and grazing	Granules, gravel, pebbles, drift sand	48	70–130
Ahmadi-Al-Daher	Grazing, oil exploration and production, and urban expansion	Gravel, sand silt	17	30–80

Table II. Criteria for assessment of soil compaction and hydrological deterioration

Status criteria	Land degradation classes		
	Slight	Moderate	Severe
Area covered with aeolian sand (%)	<30	30–70	>70
Removal of top soil by water (%)	<25	25–50	>50
Decrease of total plant cover (%)	<25	25–75	>75
Bulk density ($g\,cm^{-3}$)	1·5	1·5–1·8	>1·8
Soil resistance ($kg\,cm^{-2}$)	<40	40–75	>75
Less soil infiltration capacity (%)*	0	50–75	75–100
Soil crust and sealing	No	Yes	Yes

*In comparison with status in protected site in the same area.

soil samples were air-dried in an oven at 105°C for approximately 24 hours. The bulk density was calculated as the oven dried mass divided by the original volume of the soil sample.

Infiltration Capacity

A double-ring infiltrometer was used to measure the initial infiltration rate. The infiltrometer consisted of two metal rings (20 cm high) driven about 5 cm into the topsoil ground surface. Both rings were filled with water. The outer ring (30 cm in diameter) supplied water that migrated laterally and at the same time saturated the soil next to the inner ring. A scale was fixed in the inner ring to measure the infiltration of water into the soil at various time intervals during the experiment using a stopwatch. The duration of each test was 30 minutes.

Land Degradation Assessment

Based on Landsat TM images of 1992, 1995 and 2000, aerial photos of 1992 and 1997, field surveys and other research work (Misak and Al-Dousary, 1997; Shahid *et al*., 1999; Al-Awadhi and Misak, 2000; and Misak *et al*., 2001), the main land degradation indicators in Kuwait, in general, and in the study areas specifically, were delineated. A land-use map of the KISR (1999) study together with filed investigations were used to assess land use and identify causes of land degradation in the study areas.

To assess the status of land degradation in the four areas studied, the criteria for assessment of the vegetation cover, wind erosion and water erosion suggested by Kharin *et al.* (1999) were applied. Wind and water erosions were assessed based on field observations and aerial photos of the extent of aeolian sand sheets and gullies/rills, respectively. In addition, criteria for the assessment of soil compaction (soil crusting and sealing and soil resistance) and hydrological deterioration (soil infiltration), relative to each other, were proposed and considered by the authors for the local conditions of the studied areas (Table II).

RESULTS

Vegetation Assessment

An overall view of the vegetation cover in the studied areas reveals that there is a significant build up of vegetation cover and litter in the protected sites compared with the same parameters in the surrounding open sites (Table III). The percentage of decrease in total vegetation varied from 6·4 per cent to 58·1 per cent in open sites while the difference for litter varied from 32·2 per cent to 77·3 per cent. Other coverage included gravel deposits, which are relatively lower in value percentage in protected sites than in open sites, i.e. less erosion effect. The remaining coverage is considered as bare. All coverage parameters measured were significantly different at ($p = 0{\cdot}05$) according to a simple statistical analysis (*t*-test). In general, protected/fenced sites have more vegetation and litter than unprotected sites.

Table III. Results of vegetation assessment*

Area	Parameter	Control (protected) (% cover)	Open (unprotected) (% cover)	Percent of decrease in open area
N		105	165	
Mutlaa	Litter	31·3	7·1	77·3
	Total vegetation	27·3	25·5	6·4
	Gravel	11·9	45·8	
	Bare	29·5	21·6	
N		225	225	
Sulaibiyah	Litter	17·4	11·8	32·2
	Total vegetation	46·6	34·7	25·5
	Gravel	11·0	20·1	
	Bare	25·0	33·4	
N		120	120	
Ras Al-Sabiyah	Litter	26·3	9·5	64·0
	Total vegetation	12·9	5·4	58·0
	Gravel	23·9	55·6	
	Bare	36·9	29·5	

N = number of field tests.
*No vegetation assessment was conducted in the Ahmadi-Al-Daher area due to the absence of a real protected site (control).

Table IV. Results of average bulk density tests at depth of 0–10 cm

Area	Bulk density ($g\,cm^{-3}$)		
	Control (protected)	Open (unprotected)	Percent of increase in open area
N	10	14	
Mutlaa	1·41	1·74	23·4
N	10	14	
Sulaibiyah	1·59	1·79	12·9
N	8	14	
Ras Al-Sabiyah	1·27	1·51	18·9
N	3	5	
Ahmadi-Al-Daher	1·64	1·85	12·8
Average bulk density	1·47	1·72	17·0

N = number of field tests.

In each area, the types of shrub and grass vary in density and coverage percentage. In the Mutlaa area, for example, *Moltkiopsis ciliata*, a perennial shrub, and *Stipagrostis plumosa*, a perennial grass, can be seen in both protected and grazed sites, but they are particularly abundant in protected sites, scoring about 8 plants m^{-2}. On the other hand, in the Sulaibiyah area, *Cyperus conglomeratus*, perennial sedge, is the dominant perennial in the open rangeland, comprising about 2·6 per cent of the total cover, and *Rhanterium epapposum* is the perennial dominant shrub in the protected sites, showing about 10 per cent coverage.

Bulk Density

Table IV summarizes the results of average bulk density measured in the four studied areas. The table indicates that the bulk density of soils in the open sites is greater than that of the control sites. The difference ranges between 12·8 per cent and 23·4 per cent with an average increase value of 17 per cent.

Table V. Results of average top soil penetration (resistance) tests

Area	Soil penetration (kg cm^{-2})		
	Control (protected)	Open (unprotected)	Percent of increase in open area
N	100	140	
Mutlaa	2·76	5·64	104·3
N	100	140	
Sulaibiyah	3·37	5·38	59·6
N	80	140	
Ras Al-Sabiyah	5·90	7·0	18·6
N	20	60	
Ahmadi-Al-Daher	4·76	7·86	65·0
Average penetration	4·19	6·47	61·8

N = number of field tests.

Table VI. Results of average infiltration tests

Area	Infiltration rate (cm min^{-1})		
	Control (protected)	Open (unprotected)	Percent of decrease in open area
N	8	15	
Mutlaa	1·13	0·62	45·0
N	12	18	
Sulaibiyah	1·37	0·66	51·8
N	8	19	
Ras Al-Sabiyah	0·68	0·32	52·9
N	3	9	
Ahmadi-Al-Daher	0·83	0·32	61·4
Average infiltration	1	0·48	52·7

N = Number of field tests.

Top Soil Resistance

As indicated in Table V, the average soil penetration rate in the open sites is greater than that in the control sites. The increase varies from 18·6 per cent to 104·3 per cent with an average value 61·8 per cent. In sites where the soil compaction value was very high due to the heavy vehicle manoeuvreing, impermeable layers were determined at about 22 cm depth.

Infiltration Capacity

As shown in Table VI, the average infiltration rate in the open sites is lower than that in the control sites. The decrease in open sites varies between 45·0 per cent and 61·4 per cent with an average value of 52·7 per cent.

Land Degradation Assessment

From field observations and measurements of the main characteristics of the study areas (*see* Table I), the following indicators of the land degradation process were identified: (1) wind erosion; (2) water erosion; (3) soil compaction and sealing; (4) soil displacement, mining and excavation; (5) vegetation degradation; and (6) surface hydrological degradation. These indicators exist almost all over the desert of Kuwait as shown on the land degradation indicators map (Figure 5), which is introduced on the bases discussed in the methodology section.

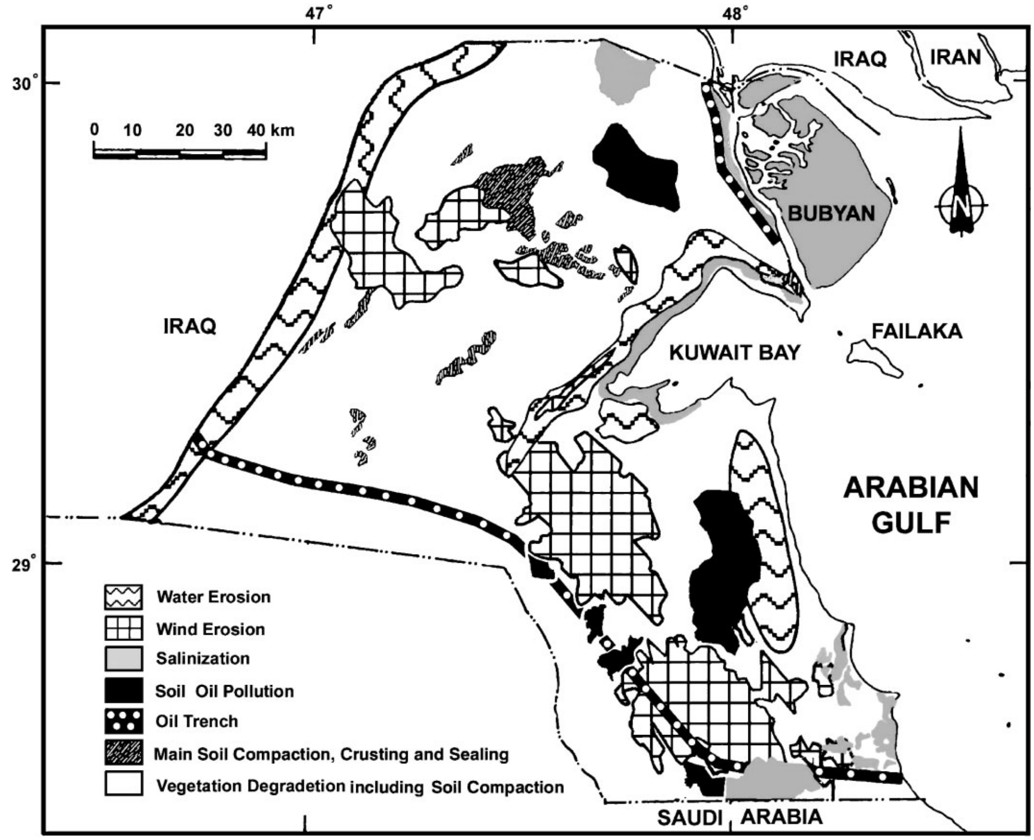

Figure 5. Mapping main indicators of land degradation in Kuwait.

Table VII. Magnitude of land degradation in the studied areas

Study area	Protected area	Class (%)		
		Slightly degraded	Moderately degraded	Severely degraded
Mutlaa	15	10	45	30
Sulaibiyah	15	10	45	30
Ras Al Sabiyah	5	25	45	25
Ahmadi-Al-Daher	0	25	35	40
Average	8·75	17·5	42·5	31·25

The overall magnitude assessment, based on the three classes (1) slightly degraded, (2) moderately degraded and (3) severely degraded in the four studied areas, is presented in Table VII and Figure 6. The moderate class of land degradation averages 42·5 per cent followed by the severe class (31·2 per cent). The slight and almost non-degraded classes constitute 17·5 and 8·7 per cent, respectively.

The human-causes of land degradation in the studied areas are identified on the basis of analysis and interpretation of field data, including current land uses and satellite images. Accordingly, the proportions of the main causes (i.e. land-use-related) are measured and presented in Table VIII.

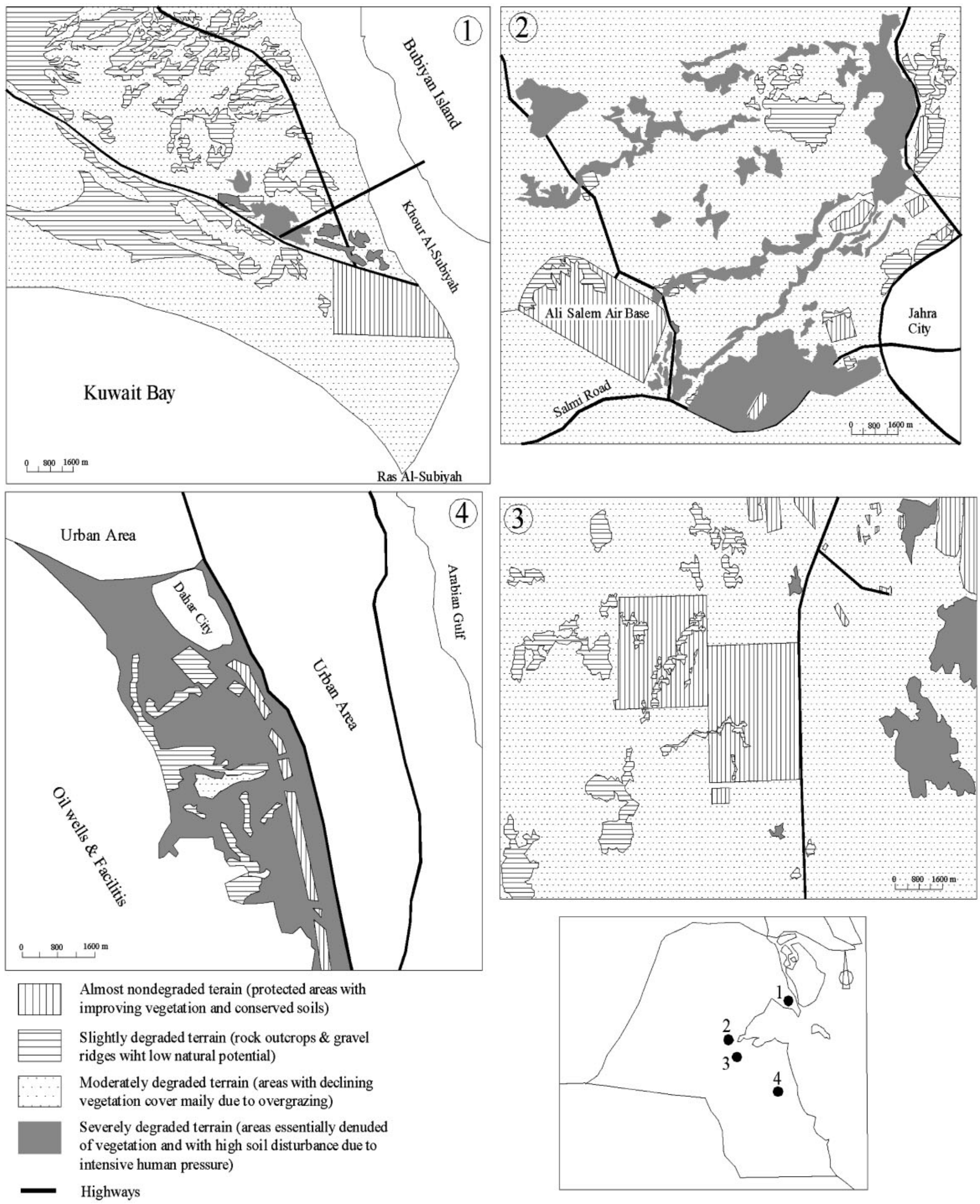

Figure 6. Land degradation status map for the study areas: (1) Ras Al-Sabiyah, (2) Mutlaa, (3) Sulaibiya, and (4) Ahmadi-Al-Daher.

Table VIII. Percentages of human causes of land degradation in the studied areas

Study area	Overgrazing	Camping and recreation	Quarrying (gravel/sand)	Military operations
Mutlaa	60	10	10	20
Sulaibiyah	75	10	5	10
Ras Al-Sabiyah	70	5	7	18
Ahmadi-Al-Daher	65	—	10	25
Average	67·5	6·25	8	18·25

DISCUSSION

In Kuwait, land degradation is one of the most disastrous ecological processes. Based on field investigations combined with remote sensing images and aerial photos several land-degradation indicators were defined in this study. Most of these indicators are attributed to the combination of population growth, economic development, drought periods, and the military activities in 1990–1991 and 2003. This is in accordance with the studies of Al-Awadhi (2001) and Al-Awadhi *et al.* (2003). These multiple functions are the main cause of land degradation on the vulnerable resources of Kuwait's desert ecosystem (Al-Awadhi *et al*., 2003). The inherent fragility of the soils, vegetation covers and micro-relief of the desert surface exacerbates this combination of causes.

Figure 5 reveals that the vegetation degradation, which is mainly due to overgrazing and human activities, is a major component of the land degradation problem in Kuwait. Human activities including the Gulf War (1990–1991), spring camping and recreation activities and surface-gravel quarrying have left many scars on the fragile desert ecosystem of Kuwait, such as compaction of topsoil, disruption of local relief and soil disturbance (Al-Ajmi *et al*., 1994; Al-Awadhi *et al*., 2003). In Kuwait over-grazing of rangelands by livestock is the most widespread cause of land degradation, and it constitutes about 67·5 per cent of the total cause (Misak *et al*., 2001). According to Misak *et al.* (2000), there are about 920 000 sheep, 110 000 goats and 23 000 camels grazing on rough desert grass and shrubs. About 10, 8, and 23·5 per cent of the overall livestock population grazes in and around Mutlaa, Ras Al-Sabiyah and Sulaibiyah, respectively. The effect of overgrazing is clearly observed in all the studied areas and especially in Mutlaa area where the vegetation cover in some sites has decreased to less than 10 per cent within the last three decades due to the dramatic increase in the number of animals in the area (Al-Awadhi *et al*., 2003).

Spring camp is a seasonal traditional practice that takes place during October to April near the population centres and along highways leading to the desert areas. This causes clearance of natural vegetation around camps (3600 m^2 on average per camp (Misak *et al*., 2002). In addition to traditional human activities, war machinery and ground fortifications used during the Gulf War and since have disturbed and bisected the desert surface. Huge amounts of soil were excavated to construct berm-trench defence systems and sandy-roads. The Iraqi troops constructed some 727 995 bunkers and trenches in different areas in Kuwait, and the total length of these systems exceeded 300 km (Al-Awadhi *et al*., 2000). On the other hand, the amount of excavated sediments resulting from the formation of a road base reached 4000 $m^3 km^{-1}$ length (Al-Ajmi *et al*., 1994). Over-exploitation of gravel deposits, which are present in a relatively thin layer over an area of about 383 km^2, i.e. equivalent to about 2·2 per cent of the total area of the country, has led to the elimination of vegetation cover and the destruction of near-surface sediments (Al-Awadhi and Misak, 2000; Al-Awadhi *et al*., 2003).

On the other hand, most of the productive lands in Kuwait face serious environmental constraints because of salinization effects (Omar and Abdal, 1994). The war damage inflicted on the infrastructure and the pollution from oil-well fires has further exacerbated these constraints. Unfortunately, very little has been done on soil reclamation and management.

In all the four areas studied, soil erosion by wind and water, due to the lack of protective vegetation cover, is a vital factor responsible for land degradation. Accelerated soil erosion is caused by overgrazing, uprooting of shrubs for fuel use, military manoeuvres and other mechanisms of human pressure. Under severe wind erosion, the infertile subsoil is exposed at the surface and thus plant growth and vigour are adversely affected. Environmentally, wind erosion has both on-site and off-site impacts. The on-site impacts include the loss of topsoil by deflation and terrain deformation by hollows, granule ripples, blowout and dunes. The off-site impacts include sand and dust storms, and sand encroachment on various facilities. During the summer, the Mutlaa area, for instance, provides an influx of sand and dust to Jahra City, located at 5 km to the south of Mutlaa area, producing environmental and health problems there.

In Kuwait, wadis, which are carved into the underlying rocks, were formed in the post-Pleistocene time when fluvial processes were predominant (Kwarteng *et al*., 2000). Usually these wadis are characterized by high permeability resulting in rapid downward movement, which thereby minimizes the risk of water erosion. Therefore wadis act as the most suitable habitat for desert shrubs and grasses, and as the main environment for to some plant species, particularly *Haloxylon salicornicum*, which plays a crucial role in topsoil fixation. Unfortunately, off-road (desert-road) intersect most of these wadis, which causes an imbalance in the hydrological cycle of the area (Al-Dousari *et al*., 2000). Around Kuwait city most of the drainage channels have been destroyed by urban expansion. The severity of water erosion in the Mutlaa area, however, is mainly attributed to intensive rainfall (40–100 mm in 3–4 h), steep slopes along Jal Az Zour escarpment, and low infiltration capacity on the foot slopes due to severe soil compaction by vehicle movement. Environmentally, water erosion has both on-site and off-site impacts. The on-site impacts include loss of topsoil by surface wash and sheet erosion, and terrain deformation by rills, gullies and mass movement. The off-site impact involves flash flooding (during heavy rain storms).

Vegetation degradation is clearly observed in the four study areas. For example, about 722 000 m^2 and 392 000 m^2 were completely cleared of vegetation cover for ground fortifications in the Mutlaa and Ras Al- Sabiyah areas, respectively. Field studies indicated that rangeland degradation results from overgrazing as well as uncontrolled human activities, such as off-road vehicles, uprooting of shrubs, gravel quarrying and other related activities. Environmentally, vegetation degradation impacts include enhancement of soil erosion by both water and wind, sealing and crusting of topsoil mainly through raindrop impact, and depletion of soil fertility and productivity.

The surface hydrological degradation in the studied areas is mainly attributed to soil compaction due to off-road vehicles on soil with low stability. The wide range of increases in soil penetration in the four study areas is attributed to differences in soil textures and human pressure on open sites. In the Mutlaa and Ras Al-Sabiyah areas, surface hydrological degradation is more severe than in the Ahmadi-Al-Daher and Sulaibiyah areas. This is attributed to significant surface deformation in the first two areas. The high bulk density usually reflects the high degree of the soil compaction and results in low infiltration rates as well as the restriction in plant root penetration (Misak *et al*., 2002). Environmentally, surface hydrological degradation impacts include disturbance of the delicate balance between water, vegetation and soil, as well as the creation of new microhabitats and the decline of the existing ones.

CONCLUSIONS

Kuwait faces a number of land-degradation interventions of varying degrees such as soil erosion by wind and/or water, deterioration of vegetation cover, soil crusting and sealing, soil compaction, soil contamination by oil, and soil salinization. Based on the percentage of vegetation cover and physical properties of the soil, three classes of land degradation, namely severe, moderate and slight, are identified. The average percentage distributions of theses classes in the studied areas are found to be 31·25, 42·5 and 17·5 per cent for the severe, moderate and slight classes, respectively. Development of a national action programme to control land degradation is strongly recommended at this stage where moderate to severe land degradation prevails in most of the desert surface of Kuwait. Introducing environmentally sound, socially acceptable and economically feasible land-use systems, especially for grazing, camping and reclaiming polluted or salinized soils should be urgently attended to by the Kuwait Government.

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