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Land and vegetation degradation in war-affected areas in the Sabah Al-Ahmad Nature Reserve of Kuwait: A case study of Umm. Ar. Rimam

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period. Soil and vegetation assessment also confirmed that the natural recovery did not restore land and vegetation to their pre-disturbance status.

Keywords: Protected areas; Soil compaction; Military disturbance; Restoration of native vegetation; Infiltration rate; Damage assessment; Vegetation cover; Bulk density

1. Introduction

The Sabah Al-Ahmad Nature Reserve of Kuwait (formerly known as The National Park of Kuwait) was established in 1990 to protect and conserve the natural heritage of Kuwait while at the same time, provide outdoor recreational, educational and research opportunities. It combines different landscape features and diverse plant and animal life forms representative of both coastal and terrestrial ecosystems. Prior to the 1990 Iraqi invasion, the reserve contained four main plant communities *Rhanterium epapposum* (60%), *Haloxylon salicornicum* (30%), *Nitraria retusa* and *Zygophyllum qatarense* (10%), in addition to salt marsh vegetation along the coast (Omar et al., 1986). An action plan to conserve and enrich natural biodiversity and the park's physical resources was in place at the time of the invasion (Omar, 1982; Taha and Omar, 1982; Omar and Taha, 1984; Omar and Al-Shuaibi, 1986; Omar, et al., 1998). Iraqi invasion and subsequent occupation of Kuwait disrupted all planned activities in the reserve and severely damaged its infrastructure, land, and native vegetation and wildlife habitats. During the occupation, the damage was related to physical disturbance to the soil due to the construction of bunkers and foxholes, laying of mines and increased movement of heavy equipment and personnel carriers. In the post-liberation period, the detonation of munitions in large pits resulted in depressions and the off-road movement of heavy machinery during the disposal operations caused most of the damage particularly in Umm. Ar. Rimam area of the reserve. Preliminary observations indicated that these activities had disturbed established soil horizons, disrupted ongoing pedogenic processes, resulted in severe soil compaction and adversely affected vegetation structure, species composition and plant production (Omar et al., 1998).

With extreme temperatures, low and erratic rainfall and high evaporation rates, soil and plant recovery in arid environments is inherently slow (Kockelman, 1983; Prose and Wilshire, 2000). Previous studies have indicated that natural recovery of severely disturbed and compacted desert soil is extremely slow and, some researchers have suggested that the subsurface compaction may not recover at all. The establishment of desert plants may be significantly retarded in compacted soils (Adams et al., 1982). Using a logarithmic model, Webb (2002) estimated that the time required for 85% compaction recovery ranges from 105 to 124 years. Prose and Metzer (1985) estimated that it requires 8–112 years for vegetation to recover to pre-disturbance conditions on moderately compacted desert sites, and 100–3000 years on heavily compacted sites. The study reported in this paper was undertaken during 1999–2001 to examine the type and magnitude of damage to soil and native plants and the natural recovery of soil and vegetation 10 years after the severe damage caused by military activities in the Umm. Ar. Rimam area of the Sabah Al-Ahmad Nature Reserve of Kuwait. The reserve was protected from human activities during the post-liberation period and immediately after the clearance of mines and ammunitions in 1994.

2. Material and methods

2.1. Climate and geomorphology of experimental area

Kuwait occupies approximately 17,800 km^2 of the northeastern part of the Arabian Peninsula, between latitudes 28°30′ and 30°05′N and longitudes 46°33′ and 48°30′E. It is bounded on the south by the Kingdom of Saudi Arabia on the north and west by Iraq, and on the east by the Arabian Gulf. Kuwait's climate is characterized by harsh summers and mild winters. The temperature fluctuations are large, with means during the warmest and coolest months ranging between 46.2 and 6.9 °C (Annual Statistical Abstract, 1998). Frost is fairly common in winter. Annual rainfall is low and highly variable, averaging about 120 mm. Evaporation is very high, ranging from 3.0 to 14.1 mm d^{-1}. The relative humidity is generally low, and strong, dry and hot, northwesterly winds prevail during summer, particularly in June and July.

The Umm. Ar. Rimam is located in the desert plain habitat in the nature reserve and consists of deep depressions, wadis (dry stream bed that is subjected to occasional flash flooding) and playas (the dry and nearly level lake plain occupying the lowest parts of the closed depression). The area slopes gently in the north-westerly direction with a slope angle $<5°$. The undisturbed soil in the study site contains 80–96% sand and 3–6% silt. While the surface layer (0–50 cm) contains 1.4–11.3% gravel, the subsoil (50–200 cm) consists of a hard to very hard lime or lime silica hardpan (*gatch*) at varying depths (Omar et al., 1986). The soil is non-saline with ECe ranging between 0.3 and 1.5 mS cm^{-1}. The soil is low in chlorides (0.3–7.7 meq l^{-1}), bicarbonates (0.7–1.0 meq l^{-1}), sulfates (1.4–11.7 meq l^{-1}), organic matter and most plant nutrients (Omar et al., 1986).

2.2. Pre-invasion vegetation in the Umm. Ar. Rimam area

During the pre-invasion period, the Umm. Ar. Rimam area hosted a wide range of plant species. Major plant communities were *Calligonum polygonoides* L., *Ochradenus baccatus* Delile, *Pennisetum divisum* (Gmel) Henrard, and *Launaea mucronata* (Forssk.) Muschl.. *Lycium shawii* Roem. and Schult. was scattered along the wadis (dry valleys filled with alluvial sediments). The common species of steep wadis were *O. baccatus* Delile. and *P. divisum* (Gmel) Henrard, whereas the shallow wadis contained *H. salicornicum* (Moq.) Bunge Ex Boiss., and *R. epapposum* Oliv. *Gynandriris sisyrinchium* Parl., and *Malva parviflora* L., were the most common plants in the playas (low-lying portions of the desert basin that collected rainfall and sediments). The common annual species were *Anthemis deserti* Bioss., *Arnebia decumbense* Vent. Coss and Karl., *Bromus tectorum* L., *Malcolmia grandiflora* (Bunge) O. Kuntze., *Gagea raticulata* (Pall.) Schult. Et Schult. F., *Calendula arvensis* L., *Cardus pycnocephalus* L., *Centauria phyllocepha, Savignya parviflora* (Delile.) Webb., *Lotus halophilus* Boiss.and Sprun., *Cutandia memphitica* (Forssk.) Trabut in Batt. and Trab., *Emex spinosa* (L.) Campd., *Ifloga spicata* (Forssk.) Sch.Bip., and *Picris babylonica* Hand. Mazz.. The vegetation cover during the pre-invasion period ranged between 45 and 65% of the total surface area (Omar et al., 1986).

2.3. Selection of study site

Based on the biophysical features the nature reserve's area was previously divided into five sections (coastal area, coastal sand dune area, escarpment, back slope and depressions). The site selected for this study is located in the Umm. Ar. Rimam depression of the reserve. For selecting the study site, several potential sites in the Umm. Ar. Rimam depressions were individually assessed by a multidisciplinary team consisting of experts in range management, horticulture, environmental science and soil science using damage indicators, such as nature and extent of damage, resemblance of damage to other areas, importance of the area to the aim's of reserve and need for undertaking immediate rehabilitation measures. A 12 ha ($600 \times 200\,m^2$) site in the wadi that contained 14 large refilled munition disposal pits which were randomly scattered throughout the site, was selected for this study. Preliminary field observations indicated that the area between pits was severely compacted due to the movement of heavy machinery during the Explosive and Ordinance Disposal (EOD) operations. The study site also contained off-road vehicle tracts and visually undisturbed areas.

2.4. Damage assessment

The study area contained four main types of disturbances (pits, compacted area between pits, road tracts and visually undisturbed control). Semi-quantitative field survey supported by laboratory analyses of soil samples was employed for assessing the nature and extent of damage caused by various war-related activities (Omar et al., 2002). The study area was thoroughly assessed by a multidisciplinary team, which systematically traversed the site and recorded the relevant information on every feature observed on the ground (presence of metal fragments and gatch pieces, erosion of top soil, exposure of gatch layer and uneven topography).

The nature of the soil in the disturbed (area covered by munition disposal pits, compacted areas) and visually undisturbed (control) areas was examined by augering and collecting soil samples from identifiable horizons of the profile. A total of 66 soil samples (58 from disturbed and eight from control area) were collected from the study site. In addition, a core of soil was collected from each area for determining bulk density. The bulk density was determined by measuring the oven dry weight of soil core of a known volume (Page et al., 1982). Porosity was calculated using bulk density values and standard particle size density ($2.65\,g\,cm^{-3}$).

Soil samples were air-dried at around 30 °C until they were fully dry and were sieved through a 2-mm sieve to separate fine (<2 mm) and coarse fractions (>2 mm) according to the United States Department of Agriculture (USDA) specifications (Soil Survey Division Staff, 1993). The coarse fraction was discarded after recording its weight. The fine soil fraction was analysed for various physical (color and saturation percentage) and chemical (electrical conductivity, pH of saturated paste and $CaCO_3$ levels) parameters. Soil color was determined by the Munsell® Color Chart (Munsell, 1998). pH and EC of saturated soil paste were estimated using USDA (1996, Method 8a). Saturation percentage was calculated based on the amount of water required to prepare the saturated soil paste. $CaCO_3$ content was measured using calcimeter (USDA, 1996).

2.5. *Infiltration rate and penetration resistance*

Infiltration rates were measured in pitted, compacted, road tracts and undisturbed control areas. Fall of water head (level) in the double-ring infiltrometer at fixed time intervals was used to calculate the rate of movement of water through the soil profile.

The penetration resistance was measured using the Bush soil penetrometer (model SP 1000). Specifications used for the test include sample type (2:25 readings per insertion at 2-cm-depth intervals), cone diameter (12.83 mm) and pressure [pressure ($kg\,cm^{-2}$)] = cone resistance/(Πi) radius^{-2}). The data from three insertions were averaged for each depth and entered into a computer. Penetration curves were prepared by plotting cone resistance against depth of insertion (i). The interpretation of these curves allowed the identification of soil compaction in the profile. Eight penetration tests were carried out in each disturbance type (refilled pits, compacted area, road tracts and undisturbed control).

2.6. *Vegetation assessment*

Vegetation was assessed inside and outside of each pit in the study area. A random quadrat placement method was used to estimate ground cover (Bonham, 1989). Five $1 \times 1\,m^2$ quadrats were randomly located both inside and outside each pit and the percentage of gravel, litter, bare ground and total vegetation cover were visually estimated. The data was statistically analysed using the S-Plus package and one-way ANOVA test to compare means. These results were compared with the previously reported data for the undisturbed areas in this nature reserve.

2.7. *Impact rating and delineation of impact zones*

Various features observed on the ground (such as loss of top soil, accelerated water erosion, exposure of gatch, uneven topography, compacted road tracts, mixing of broken gatch pieces in soil profile, loss of vegetation, altered infiltration rates and altered penetration resistance) and the laboratory characterization of the soil (changes in physical and chemical properties) were rated on a scale of 0 (no impact or disturbance) to 4 (very severely disturbed) and a cumulative score was derived for each disturbance type to determine the severity of damage. This information has been used in the planning of a pilot rehabilitation study to restore the degraded land and vegetation to their pre-disturbance levels.

3. Results

3.1. Field assessment of damage

A significant portion of the study site is severely disturbed due to the excavation of several munitions disposal pits, detonation of munitions, refilling of these pits with gatch-mixed soil and compaction of soil surface caused by off-road vehicles and the use of heavy machinery during excavation and refilling operations. The munition disposal pits accounted for 11.2% of the 12 ha total area of the study site, whereas compacted areas between pits and road tracts covered 36.4% and 3.6%, respectively, of the total area. The remaining 58,520 m^2 area (48.8% of the total) was relatively undisturbed. The area covered by individual pit varied from 546 to 1659 m^2.

Field observations showed the presence of shattered metal and excavated gatch pieces both on the surface and up to a depth of about 200 cm in the soil profile in the pitted areas. Red mottling was observed below 100 cm depth in some pits, which is an indication of contamination of soil with munitions materials. The munitions disposal activity destroyed the original horizons, which made it difficult to identify distinct layers and the soil class in the pitted area. Due to the loss of top soil, gatch pieces were clearly visible on the surface at several places. The surface and the subsurface soils in areas between pits and under road tracts were severely compacted, contained larger gatch pieces and offered greater resistance to augering. In contrast, the gatch layer was intact and occurred at greater depths (beyond 100–150 cm from the surface) in the undisturbed area (control).

3.2. Physical and chemical properties

The excavation and refilling operations altered some physical and chemical properties of soils (Tables 1 and 2). In the undisturbed area the salinity (ECe), which ranged between 0.8 and 6.21 $d\,Sm^{-1}$, increased with depth. In contrast, soil samples at all depths from munition disposal pits generally had low ECe values ($<4\,dS\,m^{-1}$), except for two samples (50–100 cm layer in pit no. 4 and 100–150 cm layer in pit no. 5) that had higher ECe levels (4.3 and 4.8 $dS\,m^{-1}$, respectively). Therefore, these soils are categorized as non-saline. The soil salinity in the compacted area between pits ranged between 4.8 and 5.6 $dS\,m^{-1}$. Soil pH (7.09–8.34), $CaCO_3$ content (0.6–19.6% meq) and saturation percentage (20.6–49.0) were highly variable and did not show any definite trend both within damage types and depths. However, soils from pitted and compacted areas contained greater amounts (as high as 54.0%) coarse fractions than the control soils.

Detonation of live munitions contaminated the soil profile with high levels of iron (3600–22,000 $mg\,kg^{-1}$), copper (1.4–14.6 $mg\,kg^{-1}$), manganese (31.4–218.0 $mg\,kg^{-1}$),

Table 1
Selected soil properties in refilled pits, compacted and undisturbed areas

Impact categories	Depth (cm)	Electrical conductivity ($dS\,m^{-1}$)	pH	$CaCO_3$ (% eq)	Saturation percentage	Coarse fraction (%)
Refilled pit 1	0–50	0.6	7.78	14.5	26.2	23.0
	50–100	0.6	7.89	13.9	27.8	5.0
	100–150	1.4	7.86	14.4	27.4	6.5
	150–200	3.5	7.82	16.9	29.8	8.0
	200+	2.8	7.73	13.2	38.6	9.2
Refilled pit 2	0–50	0.4	7.9	15.9	32.6	22.0
	50–100	0.4	7.92	16.5	28.6	15.0
	100–150	0.6	7.84	16.3	30.2	12.8
	150–200	0.6	7.89	16.7	31.4	9.0
	200+	0.6	7.83	14.5	29.0	7.0
Refilled pit 3	0–50	1.6	7.43	14.5	30.6	2.3
	50–100	0.7	7.85	15.5	30.6	9.8
	100–150	0.5	7.97	8.1	22.1	9.7
	150–200	0.5	8.03	2.9	20.6	6.5
	200+	0.5	7.95	0.7	21.1	9.0
Refilled pit 4	0–50	0.9	7.82	17.6	32.6	25.5
	50–100	4.3	7.83	19.1	37.1	19.0
	100–150	2.5	7.92	12.4	28.6	15.0
	150+	1.1	8.14	12.1	24.2	10.0
Refilled pit 5	0–50	2.3	7.84	12.6	28.2	16.8
	50–100	3.2	7.98	17.0	33.5	8.7
	100–150	4.8	7.79	15.6	30.6	6.0
	150–220	3.6	7.90	2.9	26.2	1.6
Refilled pit 6	0–10	1.2	7.09	9.0	25.8	5.3
	10–50	0.3	7.77	17.8	33.5	3.3
	50–200	0.4	7.91	10.1	33.1	3.2
	200–225	0.56	8.00	17.6	41.9	17.0
	225–250	0.66	7.96	7.1	36.7	2.1
	250+	0.77	8.07	2.1	25.8	6.0
Refilled pit 7	0–20	0.48	7.78	6.7	22.6	0.9
	20–60	0.43	7.64	9.3	24.2	2.0
	60–150	0.5	7.68	4.5	21.4	1.1
	150–220	0.48	7.8	1.0	24.6	2.3
Refilled pit 8	0–50	0.65	7.73	8.7	21.1	23.0
	50–100	0.33	7.57	15.3	28.6	15.0
	100–150	0.41	7.8	15.4	32.7	10.0
	150–200	0.46	7.93	10.0	21.2	10.0
Refilled pit 9	0–60	1.95	7.79	13.6	32.3	1.1
	60–225	0.32	8.19	0.6	25.4	0.6
Refilled pit 10	0–50	0.7	8.22	16.9	28.6	10.0
	50–150	2.9	7.84	9.2	20.6	0.9

Table 1 (*continued*)

Impact categories	Depth (cm)	Electrical conductivity ($dS\,m^{-1}$)	pH	$CaCO_3$ (% eq)	Saturation percentage	Coarse fraction (%)
	150–200	1.17	8.13	1.7	21.8	1.5
	200+	1.16	8.3	5.6	20.6	3.3
Refilled pit 11	0–30	0.34	7.98	15.4	28.2	4.0
	30–50	0.41	7.99	19.2	31.9	15.3
	50–200	2.16	8.05	19.6	43.1	0.6
	200–250	2.69	8.34	1.50	23.4	0.9
Refilled pit 12	0–25	0.35	8.06	9.3	22.2	23.0
	25–50	0.39	7.97	10.6	32.7	1.8
	50–200	3.20	8.13	17.6	41.1	2.8
	200–250	1.41	7.78	2.6	22.6	0.4
Refilled pit 13	0–60	0.63	7.71	10.4	26.2	9.1
	60–150	1.24	7.86	12.9	26.6	8.8
	150–200	3.88	7.73	10.6	36.7	9.0
	200+	2.25	7.97	3	20.6	2.5
Compacted area	0–5	4.8	7.55	12.3	27	45.0
	5cm–30	5.6	7.54	16.6	43	48.0
	30+	5.2	7.73	18.4	49	54.0
Control 1	0–40	0.8	7.67	8.2	24	0.0
	40–60	1.19	7.63	9.5	26	0.0
	60–125	6.21	7.65	11.6	31	8.0
Control 2	0–30	1.37	7.55	7.2	21	0.0
	30–60	1.68	7.79	11.4	22	0.0
	60–105	5.51	7.55	6.1	27	0.0
	105+	3.06	7.55	2.9	25	0.0

nickel (3.1–49.8 $mg\,kg^{-1}$), lead (<0.1–5.3 $mg\,kg^{-1}$), vanadium (9.2–33.3 $mg\,kg^{-1}$) and zinc (3.4–23.8 $mg\,kg^{-1}$). Normally, the upper layers up to a depth of 100–150 cm contained higher levels of these elements than the deeper layers (the 150–200 cm or deeper layers) (Table 3). The values are much higher compared to those normally observed in the undisturbed (control) soils in Kuwait (the range of concentrations measured are 0.96–5.0 $mg\,kg^{-1}$ nickel, 0.36–1.4 $mg\,kg^{-1}$ lead and 4.8–7.0 $mg\,kg^{-1}$ vanadium (Omar et al., 2003)).

3.3. Infiltration rate

The infiltration rate of natural undisturbed soil was higher than that of soils in the munition disposal pits (Table 3, Fig. 1). The average steady-state infiltration rate ranged from 3.6 $mm\,min^{-1}$ in refilled pits to 13.2 $mm\,min^{-1}$ in undisturbed control.

Table 2
Trace metals contents in soils from refilled munition pits

Pits	Depth (cm)	Trace metals (mg kg^{-1})						
		Cu	Fe	Mn	Ni	Pb	V	Zn
1	0–50	11.4	16000	213.0	47.3	3.7	31.7	21.5
	50–100	12.8	17000	210.0	47.4	1.6	31.8	22.2
	100–150	1.9	4300	38.8	6.1	<0.1	17.2	5.6
	150–200	4.2	7700	90.1	14.3	<0.1	22.2	9.4
	200+	2.0	4900	47.8	5.4	0.5	18.7	7.0
2	0–50	13.6	17000	218.0	5.1	4.2	31.9	23.7
	50–150	6.7	11000	132.0	26.9	2.2	20.7	13.8
	150–200	2.1	4800	45.4	6.1	<0.1	13.5	5.3
	200+	1.4	3600	31.4	3.1	<0.1	9.2	3.4
3	0–25	5.1	9800	123.0	22.5	0.4	20.0	10.6
	25–50	11.4	19000	189.0	43.0	3.4	29.0	18.9
	50–200	14.6	22000	216.0	49.8	5.3	33.3	23.8
	200–250	2.7	5900	52.0	8.0	0.1	15.6	6.1
4	0–60	6.2	11000	128.0	23.6	0.2	20.0	10.8
	60–150	9.5	17000	186.0	34.5	5.9	34.8	18.3
	150–200	13.0	19000	202.0	43.4	2.8	31.1	21.6
	200–250	3.1	6200	57.5	9.5	<0.1	14.8	6.3

Table 3
Infiltration rate, penetration resistance, bulk density and porosity of soils under various damage types

Damage category	Infiltration rate (mm min^{-1})	Penetration depth (cm)	Bulk density of wet soil (g cm^{-3})	Bulk density of dry soil (g cm^{-3})	Porosity (%)
Refilled munition pits	3.6a	10a	1.98a	1.72a	25.0a
Compacted areas	2.5a	6a	1.82a	1.57a	31.0a
Road tracts	0.8a	2a	2.04a	1.70a	33.0a
Undisturbed control	13.2b	50b	1.96a	1.66a	26.0a
Correlation coefficient (r) with damage severity	−0.99	−0.98	−0.67	−0.63	0.47

Notes: Infiltration rate was measured using double-ring infiltrometer. Penetration depth was determined using Bush penetrometer. Damage severity is based on a cumulative impact rating scores using various field and laboratory parameters listed in Table 5.

Soils under road tracts had the least (0.8 mm min^{-1}) infiltration rate. The wetting zone in the disturbed and control soils ranged between 240 and 270 mm, respectively. The bulk density of dry soil in the control area was 1.66 g cm^{-3} compared to

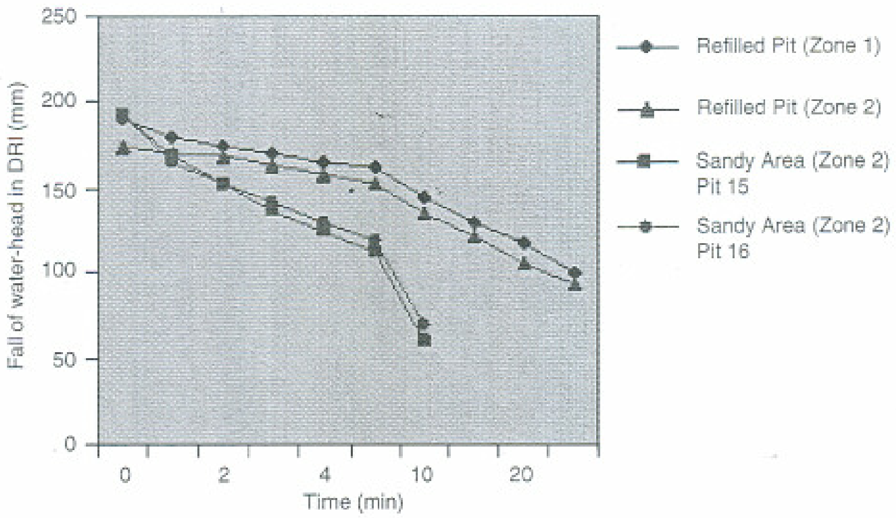

Fig. 1. Infiltration tests in refilled pits and sandy control areas.

1.72 g cm^{-3} in pits. Dry soil porosity was 25% and 35% in the pitted and undisturbed control area, respectively.

3.4. Hydraulic properties (field observations)

A number of holes were made in the study site to evaluate the depth of rainwater percolation 2 months after receipt of approximately 60 mm rain between December and February. The soil in munition pits was moist to a maximum depth of 40 cm. In contrast, the undisturbed control moist soil occurred to a depth of 90 cm, although the 8–10 cm layer near the surface was relatively dry. This is normal in sandy soils where capillaries are not formed due to the presence of macropores. This also illustrates that the soil in refilled pits was severely disturbed by excavation and refilling of pits during the munition disposal operations.

3.5. Penetration resistance

Excavation of pits through hard gatch and subsequent refilling with gatch mixed soil material resulted in greater compaction of the subsurface soil. This was evident from the fact that the penetrometer was able to penetrate only up to 10-cm depth in the refilled pits compared to 50 cm in the undisturbed control soils (Table 3; Fig. 2). Penetration depth was the least (2–5 cm depths) in compacted areas between the pits and in road tracts areas.

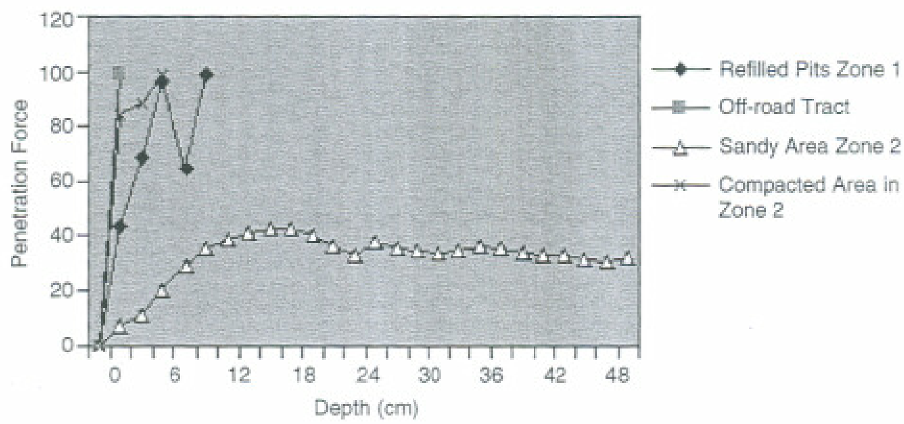

Fig. 2. Penetration resistance as a function of soil depth in refilled pits, compacted areas, off-road tracts and undisturbed control areas.

3.6. Vegetation assessment

The total vegetative cover averaged 7.3% and 1.3% inside and outside the pits, respectively (Table 4). However, these values are significantly lower compared to those recorded in this (45–65%) and other areas (average 25.0–27.7%) of Kuwait during the pre-invasion period (Omar et al., 1986). Gravel coverage was significantly higher outside the pits, scoring more than 60%. Bare ground without gravel scored higher inside the pits, averaging 56%. Litter did not vary inside and outside the pits. The overall assessment of the area indicated that the excavation of soil for detonation of ordinance created depressions, which trapped wind blown sand and seeds from adjacent areas. These low lying areas retained rainwater and created better moisture regime in the surface layer for seed germination and initial seedling establishment. However, not all of the pits showed this significant difference. Table 4 shows that the vegetation inside the pits ranged between 0% and 37%, whereas it ranged between 0% and 7.8% in the compacted areas between pits. Pits nos. 4 and 5 were the only pits that showed a significant difference in the percentage of vegetative cover inside. This could be due to greater soil depth and availability of sufficient moisture to plants.

The composition and the frequency of species in the disturbed area were different from the adjacent undisturbed areas. *Stipa capensis* Thumb. (annual grass) and *Plantago boissieri* Hausskn. and Bornum. (annual herb) were the most dominant species in the disturbed areas (inside the pits and in compacted areas around the pits), although a few more species (*C. pycnocephalus* L., *P. babylonica* Hand. Mazz., *Schimpera arabica* Hochst., *A. deserti* Boiss and *Gagea reticulate* (Pall) Schult and Schult.f.) occurred at low frequencies. The studies conducted by El-Sheikh and Abbadi (2004) during the spring of 2001 showed that the undisturbed (control) areas in this habitat contained the highest number of species (98) and had a plant coverage of 51.6%. Major contribution to the plant cover was made by annual herbs and

Table 4
Vegetation analysis inside and outside refilled munition pits

Mean value[a]	Inside pit	Outside pit		Inside pit	Outside pit
Pit no. 1			Pit no. 8		
Gravel	47.0a[*]	65.0a	Gravel	35.0b	87.0a
Litter	0a	0a	Litter	11.0a	2.0a
Bare	37.0a	34.0a	Bare	54.0a	11.0b
Total vegetation	16.0a	0.2a	Total vegetation	0a	0a
Pit-2			Pit-9		
Gravel	22.0a	38.0a	Gravel	50.0a	40.0a
Litter	4.0a	1.2a	Litter	4.6a	5.0a
Bare	67.0a	58.0a	Bare	42.2a	47.4a
Total vegetation	7.0a	2.4a	Total vegetation	3.2a	7.6a
Pit-3			Pit-10		
Gravel	29.0a	49.0a	Gravel	13.0b	92.0a
Litter	3.0a	2.0a	Litter	2.0a	4.0a
Bare	58.0a	48.0a	Bare	84.0a	4.0b
Total vegetation	10.0a	1.0a	Total vegetation	1.0a	0a
Pit-4			Pit-11		
Gravel	54.0b	90.0a	Gravel	6.0a	6.0a
Litter	1.0b	10.0a	Litter	1.0a	9.0a
Bare	39.0a	0b	Bare	94.0a	85.0a
Total vegetation	6.0a	0b	Total vegetation	1.0a	0a
Pit-5			Pit-12		
Gravel	39.0b	90.0a	Gravel	76.0a	83.0a
Litter	1.0b	6.0a	Litter	1.0a	3.0a
Bare	23.0a	4.0a	Bare	23.0a	13.0a
Total vegetation	37.0a	0b	Total vegetation	0a	1.0a
Pit-6			Pit-13		
Gravel	5.2b	46.0a	Gravel	29.0a	9.0b
Litter	1.4a	2.0a	Litter	1.0a	1.8a
Bare	90.4a	52.0a	Bare	68.0b	85.2a
Total vegetation	3.0a	0a	Total vegetation	2.0a	4.0a
Pit-7			Average[b]		
Gravel	38.0b	89.0a	Gravel	34.1b	60.3a
Litter	0a	0a	Litter	2.4a	3.5a
Bare	53.0a	10.0b	Bare	56.4a	34.8b
Total vegetation	9.0a	1.0a	Total vegetation	7.3a	1.3b

[*]Figures followed by the same letter in the same row are not significantly different at $p = 0.05$.
[a]Average of five 1 × 1 quadrats for individual pits.
[b]Average of 65 quadrats for all 13 pits.

grasses like *P. boissieri* Hausskn. and Bornum., *P. babylonica* Hand. Mazz., *S. arabica* Hochst., *Erodium laciniatum* (Cav.) wild, *Cutandia dichotoma* (Boiss.), *Neurada procumbens* L., *Schismus barbatus* (L.), *Stipagrostis ciliate* (Desf.) de Winter and *S. capensis* Thunb. *H. salicornicum* (Moq.) Bunge ex Boiss. was scattered throughout the undisturbed areas. Prior to the invasion, this habitat was dominated

Table 5
Impact rating of damaged areas in the study site

Damage indicators	Damage type[a]			
	Refilled munition pits	Compacted area between pits	Road tracts	Undisturbed area
Loss of top soil	4[a]	4	2	3
Accelerated water erosion	1	3	2	0
Exposure of gatch	3	4	4	1
Uneven topography	2	1	3	0
Mixing of broken gatch pieces in soil profile	4	3	3	1
Loss of vegetation	2	3	4	2
Altered infiltration rate	3	4	4	1
Altered physical properties	3	4	4	1
Altered chemical soil properties	4	3	4	1
Cumulative scores	26	29	29	10
Damage magnitude[b]	Severe	Very severe	Very severe	Low–moderate

[a]Impact rating: 0—no damage; 1—low and recoverable impact; 2—moderate impact, recoverable with less intensive rehabilitation measures; 3—severely impacted, needs active rehabilitation; 4—very severe impact, rehabilitation is essential, but may be expensive.

[b]Damage magnitude is based on cumulative score: very severe = 29–32; severe = 25–28; moderate = 17–24; low = 9–16 and no damage = 0–8.

by *H. salicornicum* (Moq.) Bunge ex Boiss., *C. polygonoides* L., *A. decumbens* Vent. Coss and Kralik, *C. pycnocephalus* L., *C. memphitica* (Forssk.) Trabut in Batt. and Trab., *I. spicata* (Forssk.) Sch.Bip., *O. baccatus* Delile, *P. divisum* (Gmel) Henrard., *L. mucronata* (Forssk.) Muschl., *L. shawii* Roem and Schult. and *G. sisyrinchium* Parl. (Samira, 1986). These observations clearly indicate that the disturbance resulted in the loss of species diversity and increase in the number of species that are either rare or endangered.

3.7. Impact rating

The cumulative impact rating score varied between 10 (undisturbed areas) and 29 (compacted areas between pits and road tracts). The areas impacted by disposal of munitions and compaction are categorized as severely and very severely disturbed areas, respectively (Table 5). The severely disturbed areas require more intensive rehabilitation measures to restore soil and vegetation to their original status than less or moderately disturbed areas.

4. Discussion

In Kuwait, loss of biological diversity and desertification are the most serious ecological problems now. The main causes of desertification in Kuwait are harsh climatic conditions, increased human pressure, overgrazing and Gulf war activities (Omar, 1990). The inherent fragility of soils and loss of native vegetation cover have accelerated land degradation further (Al-Awadhi et al., 2003). A number of plant communities in the nature reserve have become either rare or endangered by the Gulf war crisis. Under these circumstances, enforcement of protection measures and restoration of plant diversity to their original status assume greater importance now than ever before.

On-site assessment and analysis of soil samples for a number of parameters (physical disturbance, chemical pollution, and physical and chemical characteristics, infiltration rate, penetration resistance and bulk density) carried out in this study provided evidences for destruction of established natural soil horizons, disruption of the natural pedogenic sequence and alteration of a number of their properties. Soil and vegetation degradation are normally associated with loss of the top soil, decline in soil fertility and productivity, increase in surface runoff, accelerated soil erosion and destruction of the seed bank in the soil.

Several researchers all over the world have shown that severely compacted soils are very slow to recover and in turn, have significant effects on ecosystem recovery (Johnson and Sallberg, 1960; Webb and Wilshire, 1980; Webb, 2002). Soil compaction increases soil's bulk density and changes other soil properties, most notably, the size distribution, strength characteristics, continuity of pores and decreases infiltration rate (Webb, 2002). These changes will have considerable long-term influence on root growth, which may affect seedling establishment and restoration of vegetation cover. Subsequent seedling growth rates may also be poor because compaction may limit access to both water and nutrients. In playas or seasonally inundated soils compaction can limit oxygen availability to roots. It may also affect natural succession process by selectively affecting the establishment and/or growth of certain species.

Although vegetation coverage inside the pits was higher than that in adjacent non-pitted areas, but are very low compared to the value reported by El-Sheikh and Abbadi (2004) for the undisturbed areas in the reserve. Because of low productivity, the recovery of native plants from abiotic (drought, high salinity) and biotic (human interference, overgrazing, cutting, off-road vehicles, disruption of soil forming process by excavation and/or refilling operations) stresses is very slow under Kuwait's environment. The harsh arid climatic conditions combined with the disruption of soil structure made it difficult for natural recovery of vegetation cover and wildlife habitats to pre-disturbance status. Whilst a quick solution for a complete reversal of land degradation and deterioration in ecosystem health under harsh climatic conditions is not available, steps can and should be immediately taken to combat this problem. These steps include continuance of strict protection measures and creation of a favorable microclimate for native plant recovery by providing temporary shelter belts, applying water conservation practices and reintroducing native plants from undisturbed areas in the reserve.

5. Conclusions

The results of this study indicated disruption of ongoing pedogenic processes, loss of top soil, severe soil compaction in some areas, reduction infiltration rate, contamination with munition materials and alterations of some chemical properties. Based on the cumulative impact rating score, areas impacted by different damages have been categorized as severely (area under munitions disposal pits) to very severely (compacted areas between pits and under road tracts) disturbed sites. Although the pits contained higher vegetation than the adjacent compacted areas, the vegetation cover was much lower than that during the pre-disturbance period. Soil and vegetation assessment also confirmed that natural recovery did not result in full restoration of land and vegetation to their pre-disturbance levels. Therefore, an active revegetation program may be needed to restore the soil and vegetation.

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