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Causes and Indicators of Land Degradation in the North-Western Part of Kuwait

أسباب ومظاهر تدهور الأراضي في المناطق الشمالية الغربية لدولة الكويت

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Abstract: In the North-Western area of Kuwait, socio-economic activities were represented by four main land uses, vehicle tracks, overgrazing, sandy berms and gravel quarries. All of these activities were delineated in the form of statistical data and three different maps, and were also compared with other case studies in Kuwait. There were 1018 facilities in the study area, 66% of these were suffering from a sand encroachment problem, and most of it without a sustainable action plan. Also, There were 878 grazing points observed in the study area, mainly concentrated in the Southern sector. Density of off-road vehicle tracks within the study area ranged widely from 0.46 to 4.27 km/km^2 with an average of 2.49 km/km^2, which are much higher than those measured in other study areas (Al-Mutlaa and Al-Salmi). It has been concluded that off-road tracks and grazing points are highly related to each other and both are found in higher densities around watering points. Furthermore, the Southern sector is highly degraded in comparison to other parts of the study area. As a result, developing a national action plan to control land degradation is strongly recommended. The principle of this action plan has been outlined in this study.

Keywords: Land degradation, Socio economic, North Western Kuwait, Vehicle tracks, Over grazing, Sandy berms, Gravel quarries.

المستخلص: تمثل الأنشطة البشرية في المنطقة الشمالية الغربية لدولة الكويت بأربع أنماط من استخدامات الأراضي هي، الطرق الترابية الناتجة عن حركة الآليات و الرعي الجائر و السواتر الترابية و محاجر الصلبوخ، هذا و يوجد 1018 منشأة في منطقة الدراسة تعاني 66% منها من مشكلة زحف الرمال. و لقد تم رصد هذه الأنماط ووضعها في خرائط تفصيلية ومقارنتها بالدراسات السابقة بمناطق أخرى مثل المطلاع و السالمي. أحصت هذه الدراسة الأنشطة البشرية من خلال رصد 878 نقطة رعي يتركز معظمها في النطاق الجنوبي لمنطقة الدراسة و تشير الدراسة الى كثافة الطرق الترابية تتراوح بين 0.45 و 4.27 كم/كم 2, في حين أن طول السواتر الترابية يصل إلي 429 كم . دلت الدراسة على مدى الترابط الوثيق بين الأنشطة البشرية مثل إرتباط كثافة الطرق الترابية ارتباطا طرديا مع كثافة نقاط الرعي مما يدل على أن هذا النشاط هو العامل الرئيسي في تدهور الأراضي بالمنطقة. لذا توصي هذه الدراسة بوضع خطط وطنية قصيرة وبعيدة المدى لوقف ومعالجة هذا التدهور.

كلمات مدخلية: استخدامات الأراضي، أنشطة بشرية، شمال غرب الكويت، حركة الأليات، الرعي الجائر، السواتر الترابية، محاجر الصلبوخ

Introduction

Land degradation is mostly attributed to human activities (Gray, 1999), and many relate it to a reduction in productivity (Misak *et al.*, 2002). (Lindskog and Tengberg, 1994) define land degradation as a reduction of the physical, chemical or biological status of land, which may restrict its productive capacity. Johnson and Lewis, 1995) define it as the substantial decrease in either or both of an area's biological productivity and usefulness due to human interference. (Johnson *et al.*, 1997) define it as any disturbance to the land perceived to be deleterious or undesirable. (UNEP, 1994) accepted the definition of land degradation as a reduction or loss of the biological or economic productivity of land resulting from various factors, including human activities and climatic variations. Degradation used to be concerned with changes in soil's physical, chemical, and biological properties (FAO, 1980). In an arid desert environment, land degradation is exacerbated by a scarcity of rainfall and intensive wind and water erosion (Al-Awadhi *et al.*, 2005).

Vegetation can provide a protective cover or boundary between the atmosphere and soil (Aweto and Iyanda, 2003); (Asefa *et al.*, 2003). There are many plant species in the Kuwaiti desert that can be categorized either as perennial or annual. There are 374 types of plant species of which 256 are classified as annual, while the rest (118) are perennial (Boulos and Al-Dosari, 1994). (Omar *et al.*, 2001) mapped eight major vegetation units in the terrestrial environment of Kuwait. The dominant plant community in the North-Western area of Kuwait is *Haloxylon salicornicum*, which is characterized by a large crown which protects the surroundings from crustation due to bombardment by rain droplets. However, *Haloxylon salicornicum* has been subjected to severe destruction by off-road transport and overgrazing. This will increase mobile sand and dust activity. In addition to the impact on aeolian transportation, the mechanical removal of natural vegetation has led to an increase in surface runoff (Al-Dousari *et al*, 2000).

Field surveys in Kuwait confirmed that vegetation cover plays an important role in preventing soil crustation (Al-Dousari *et al*, 2000). However, the existing natural plant species have been subjected to destruction by a wide variety of activities. Soil compaction by heavy machinery was studied by (Kirby *et al.*, 1997). They noticed that the void spaces were significantly decreased with the increasing passage of tyres over soil from the first pass to the eighth pass. Previous studies conclusively demonstrated that soil surface sealing and soil compaction decreased rainfall infiltration rate, and hence increased surface runoff volume (McGinty *et al.*, 1979). The infiltration capacity of the compacted soils has decreased by 35% in comparison with non-compacted soils in the Al-Salmi area in Western Kuwait (Al-Dousari *et al.*, 2000). Consequently, surface sealing and compaction increased runoff erosion. (Johnson *et al.*, 1979) claimed that the formation of a surface seal, and consequently a crust, reduced sheet and rill erosion rate and, subsequently, soil infiltration.

In Kuwait, The number of grazing animals is higher than the grazing capacity of the area in general (Omar *et al.*, 2001). Grazing of rangeland is the dominant land-use type, representing 72.3% of the total land-use (Omar *et al.*, 2001). (Misak *et al.*, 2001) showed that thousands of grazing animals and other human activities are concentrated around the watering points in Kuwait, which are sporadically distributed throughout the desert. The total number of livestock, including sheep, goats, camels and cows in Kuwait during 1980 was 447,781 with a density 25.13 km^2, of which sheep represented 89% (Table 1). In comparison to 1980, 2000 and 2001 showed that a tremendous increase in livestock had taken place, up to 793,325 and 714,884 heads respectively. Sheep represented 73% of the total number in both years. Previously, the Bedouins maintained a delicate balance between the number of their grazing animals and the carrying capacity of the pasture. Also they did not use vehicles at all. Recently this balance has been greatly disturbed, not only due to the recent control of epidemic diseases and increase in animal population, but also to the dramatic changes of the Bedouin's lives. Overgrazing around watering points in semi-arid areas can also allow sand deflation to operate more efficiently (Goudie and Thomas, 1985). Overgrazing is widely regarded as a prime cause of desertification (Goudie, 1996). If livestock management on arid lands is inappropriate, then desertification can occur (Tueller, 1998). The high albedo of soils denuded by overgrazing may result in reduced lifting of air necessary for cloud formation and precipitation, and thus lead to regional climatic desertification (Otterman, 1974).

Table 1. Animal counts and stocking density in 1980, 2000 and 2001 in Kuwait rangelands (http://www.mop.gov.kw, 22 March 2005).

Animal class	Unit in 1980	Density (unit/km^2)	Unit in 2000	Density (unit/km^2)	Unit in 2001	Density (unit/km^2)
Sheep	396,870	22.27	577,380	32.40	521,408	29.26
Goats	25,180	1.41	191,928	10.77	168,173	9.44
Camels	25,276	1.42	3,462	0.19	4,972	0.28
Cows	455	0.03	20,555	1.15	20,331	1.14
Total	447,781	25.13	793,325	44.52	714,884	40.12

The aim of this study is to delineate the impact of human pressure on desertification, and land degradation processes in the study area. To realize this objective, detailed field surveys were conducted.

Methodology

The study area (about 4269 km² representing 24% of the area of the State of Kuwait) is located in the North West of Kuwait. It is bordered by Iraq to the North West and by Saudi Arabia to the South. It extends between Latitudes 33°:00′ and, 32°:10′ North, and Longitudes 6°:90′ and 7°:40′ East (Figure 1). The study area is dissected by a network of asphalt highways; the total length of the asphalt roads is 184 km.

The land surface of the study area is composed of clastic sediments, locally known as the Al-Dibdibba Formation. The Al-Dibdibba Formation (Miocene to Pleistocene) is composed of sand and gravels with minor clay and gypsifereous sandy clay beds (Milton, 1965) and (Khalaf *et al.*, 1995). Sand and gravel act as a low conductor for solar radiation which results in the increase of temperature of the top surface and the surrounding air.

The study area, as other parts of Kuwait, has hot and dry climate. The mean air temperature in summer (July) is 37°C, with a fairly large diurnal temperature range of about 17°C in January. The highest recorded average temperature was 51°C in July 1978, while the lowest average temperature was 6°C in January, 1964 (Al-Kulaib, 1992). Precipitation is scanty and erratic. The mean total is about 112 mm/yr. Wind blows dominantly from two main directions, the northwest, and to a lesser extent from the southeast.

The study area was divided into three sub-areas: Southern, Middle and Northern sectors. The Middle sector locates between Lat. 32°:40′ and 32°:70′ North, from the Southern and Northern sectors respectively. Lengths of off-road vehicle tracks and sandy berms were measured for each square kilometre of these sub-areas based on field surveys (January, 1999 to December, 2004), aerial photographs from 1992 (scale 1:29,000) and 1997 (scale 1:40,000) and six topographical sheets (scale 1:100,000). In addition, grazing points and sand dunes were counted. The scales of the topographic sheets were readjusted to match that of the aerial photography. The output data, either measured or calculated, were used as input data to a grid system to produce contour maps. A one square-kilometer grid system is used in this study to address data to the highest level of accuracy. Data was presented on three maps. These are off-road vehicle track density, grazing points density and zones of sand dunes overlaying land use.

To quantify the socio-economic impact, specific field visits were arranged to representative sites. These included 10 grazing points, 10 gravel quarries, 3 border check stations and two military bases. Statistics on

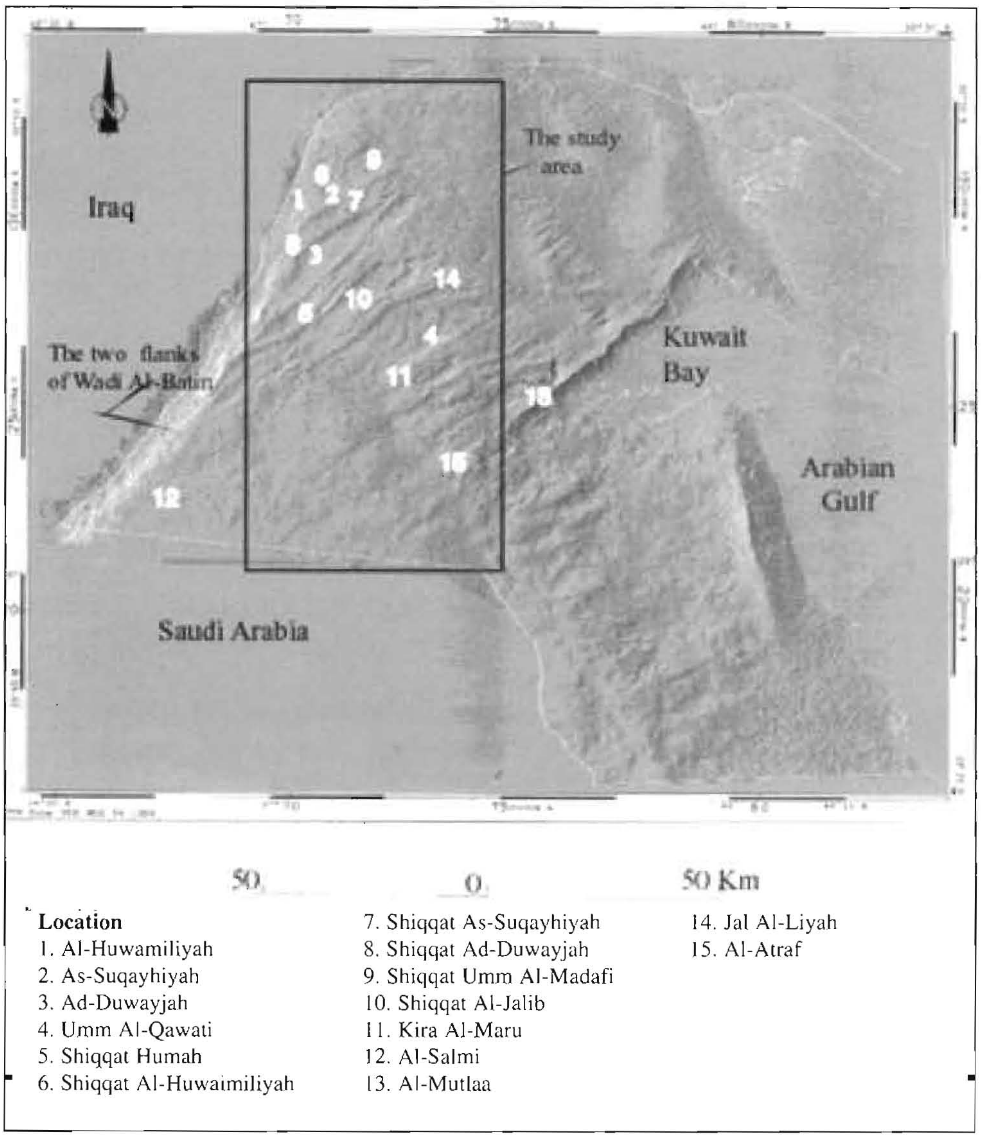

Fig. 1. A shaded relief image showing general topography of Kuwait and the study area.

labour, livestock and vehicles in these sites were collected.

In order to find the effect magnitude, infiltration tests at seven different sites were conducted using the double-ring method. In each site, two tests were carried out, one in the compacted soil within off-road vehicle tracks, and the second on the non-compacted (natural) soil. The duration of each test was 30 minutes, where the height of the infiltrating water was measured at a regular time intervals in all tests. The depth of the infiltrating water into the soil (wet zone) was also measured in a shallow pit dug for this purpose. The compressive soil strength was measured using a hand penetrometer (ST.207). Also, the bulk density was measured by the core method (USDA, 1996), and the porosity was calculated.

Results and Discussion

Population density in Kuwait increased from 2 persons/km² in 1910, to 127 persons/km² in 2002 (Table 2). Furthermore, the total number of vehicles in the country in 2002 was 907221 vehicles, which is 50.9 vehicles/km², while in 1989 it was 35 vehicles/km². Based on the results of the current study:

1500 people on average work within three military bases;
2634 people work within the grazing points;
950 laborers work in gravel quarries;
140 people work in the Poultry Company and in power-line maintenance.

Thus, the total average daily working population within the study area was 5224 persons and 4559 vehicles. The total area occupied by facilities within the study area was about 49 km², most of it being located within the southern part of the study area. Also, uman facilities are attached or linked to asphalt roads. This network of asphalt roads in the study area allows human activities to reach far inside the desert. These asphalt roads within the study area are mainly used for socio-economic activities associated with gravel quarries, grazing points, electricity power lines and pylons, military maneuvers, border check points and camping. These various socio-economic activities have both on-site and off-site effects.

The whole area is subject to uncontrolled grazing, particularly by herds of sheep and goats rather than by camels. The perennial vegetation in the study area traps mobile sand reduces the intensity of the sand encroachment problem. The results of such grazing pressures are to put stress on the already scant vegetation holding mobile sand.

Table 2. Population and vehicle densities in Kuwait (1989-2002).*

Year	Population	Desity/km²	Vehicles	Desity/km²
1910	35,636	2.0	0.0	0.0
1989	2,054,578	115.3	622311	34.9
1995	1,575,570	88.4	816471	45.8
1997	1,809,270	101.5	654667	36.7
2000	2,138,115	120.0	801555	45.0
2001	2,182,609	122.5	941091	52.8
2002	2,261,956	126.9	907221	50.9

*Ministry of Planning, (2004).

The zone of overlapped sand dunes and the land use is shown in figure (2). It has been indicated that several facilities are threatened by mobile sand either in the form of sand dunes or sand sheets. The total area that are occupied by sand dunes is 464 km² covering 11% of the study area. There are 1018 facilities within the study area, 673 of them (66% of the total facilities) were affected by sand encroachment problems (Table 3). Few of these facilities (e.g. military bases) have a sustainable action plan for controlling mobile sand.

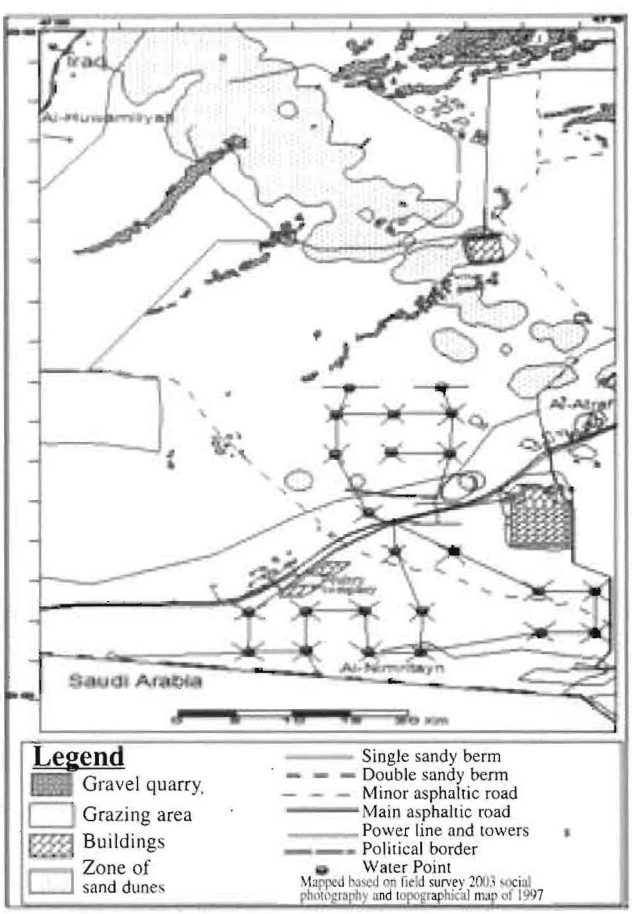

Fig. 3. Off-road vehicle tracks density map of the northwestern area of Kuwait.

Table 3. Socio-economic facilities affected by mobile sand encroachment problem in northwestern area of Kuwait.

Socio-economic Facilities	Total No.	No. of affected facilities	% of affected facilities	Sustain-able action plan
Military Bases	3	3	100	yes
Poultry companies	1	1	100	no
Border stations	3	1	33	no
Watering points	23	15	65	no
Asphaltic road	5	4	80	yes
Electrical power unit	1	1	100	no
Power lines	7	6	86	no
Fuel station	1	1	100	no
Grazing points	878	620	71	no
Farms	1	1	100	yes
Quarrying companies	95	20	21	yes
Total	**1018**	**673**	**66**	.....

(I) Off-Road Vehicle Tracks

Based on the density of the off-road vehicle tracks, five main classes were identified:

(1). Very severe off-road vehicle tracks (>3.5 km/km²).

(2). Severe off-road vehicle tracks (3 - 3.5 km/km²).

(3). Moderate off-road vehicle tracks (2 - 3 km/km²).

(4). Slight off-road vehicle tracks (1 - 2 km/km²).

(5). Very slight off-road vehicle tracks (<1 km/km²).

The very severe and severe off-road vehicle tracks prevail in the Southern sector of the study area, while the moderate class was the dominant in the Middle sector. The Northern sector shows the highest percentages of slight and very slight off-road vehicle tracks.

Figure (3) shows a contour map of off-road track density in (km/km²). About 74% of the total area of the Southern part of the study area showed very severe off-road track density (>3 km/km²), while it represents 28% and 7% of the Middle and Northern areas respectively (Table 4).

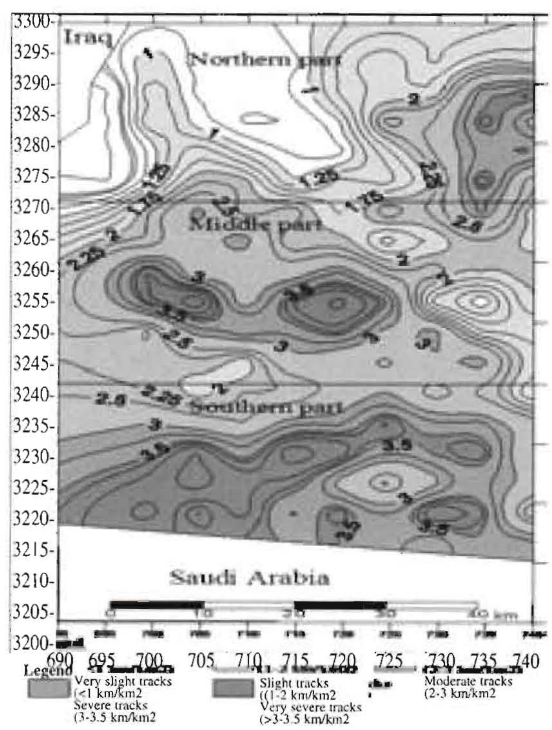

Fig. 3. Off-road vehicle tracks density map of the northwestern area of Kuwait.

Table 4. Area and percentages of the study area off-road track densities.

Off-road track	Total area		Southern area		Mid area		Northern area	
density (km/km²)	(Km²)	Total %	Area (Km²)	%	Area (Km²)	%	Area (Km²)	%
Very severe(<3.5)	606	14.2	509	39.6	68	7.5	29	1.4
Severe (3-3.5)	738	17.3	438	34.1	184	20.2	116	5.6
Moderate (2-3)	968	22.7	326	25.3	422	46.3	220	10.6
Slight (1-2)	1433	33.6	13	1.0	236	25.9	1184	57.2
Very slight (<1)	524	12.3	0	0.0	2	0.2	522	25.2
Total	4269	100	1286	100	912	100	2071	100

The density of off-road vehicles ranged widely from 0.46 to 4.27 km/km^2 with an average of 2.49 km/km^2. The high density of off-road tracks in some segments was attributed to intensive military, as well as civilian, activities. Furthermore, the off-road vehicle track density increased near grazing points, asphalt roads and highways. The contour map of off-road vehicle track density shows an increase in the middle sector of the study area due to clustering around gravel quarries and the military maneuvers area.

Table (5) shows differences in the average volume of infiltrated water, the depth of the wet zone and soil strength in compacted soils within off-road tracks and non compacted soils (natural). The average infiltration capacity, depth of the infiltrating water and soil strength drop by 58%, 52% and 11% respectively in comparison to natural soils. The off-road vehicle tracks (Figure 4) cut through most of the wadis, causing an imbalance in the hydrological cycle of the area. On the other hand, scars, ruts and grooves produced by vehicular traffic have disturbed the micro spreading system of runoff. A new pattern of minor hydrographic basins has developed. This has caused severe damage to soil and vegetation.

Fig. 4. Oblique arial photo for off-road vehicle tracks within study area in 1992

(II) Overgrazing

Through current field survey, average livestock in the study area was found to be 50 livestock/grazing point. A grazing point is defined as a small isolated livestock holding unit (Figure 5). The total livestock in the study area was 43,900 representing 6.2% of the total livestock in Kuwait.

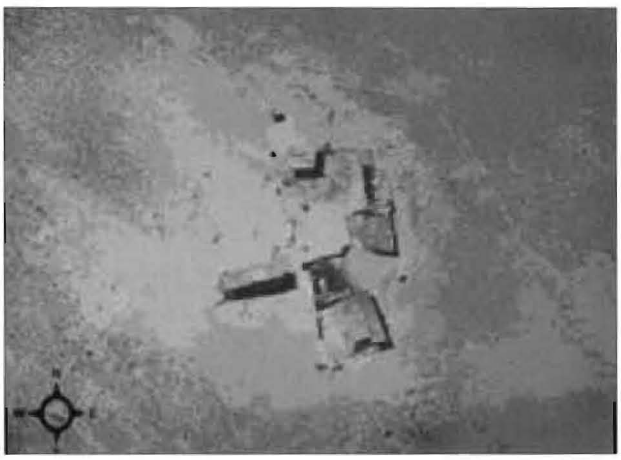

Fig. 5. Aerial photo of grazing point suffering from sand encroachment.

Table 5. Differences in average volume of infiltrated water, depth of wet zone and soil strength in off-road tracks soil and natural soils.

Sample number	Depth of wet zone (cm)		Difference %	Average volume of infiltrated water (cm3 min-1)		Difference %	Soil strength (kg cm-2)		Difference %
	Natural soil	Compacted soil		Natural soil	Compacted soil		Natural soil	Compacted soil	
St.1	17	14	18	36	30	18	7.4	7.9	7
St.2	30	5	83	112	24	79	5.9	5.9	0
St.3	45	3	93	424	14	97	2	2.1	4
St.4	54	24	56	127	45	64	8.4	8.4	0
St.5	14	11	21	23	19	20	5.2	8.5	63
St.6	30	12	62	436	35	92	7.8	7.8	0
St.7	26	19	29	88	57	35	4.2	4.3	4
Mean	31	13	52	178	32	58	6	6	11
St.D	14	7	30	176	15	33	2	2	23

Through field observation and remote sensing, especially aerial photography, the grazing points have been identified on the basis of four main characteristics:

(1) High albedo of soils in and around the grazing points.
(2) Presence of metal fences and tents, sometimes water tanks.
(3) High density of off-road vehicle track around the grazing point.
(4) Dark tone of organic matter inside fenced areas at centers of grazing points.

Grazing points varied in shape and distribution in the study area. They can be classified as isolated or compound. The isolated grazing points were usually small in size, mostly serving camel livestock and dominantly concentrated in the Northern area. On the other hand, compound grazing points comprised two or more grazing points close to each other. They were larger in size, bare of any vegetation and mainly serving sheep and goats. The compound grazing point average diameter increased with an increase in the number of grazing points inside. Most of the identified compound grazing points are concentrated in the southern area.

Based on the density of the grazing points, five main categories were noted:

(1 Very high density (>20 unit/km^2)
(2) High density (10 - 20 unit/km^2)
(3) Moderate density (5 - 10 unit/km^2)
(4) Low density (3 - 5 unit/km^2) and
(5) Very low density (< 3 unit/km^2.

The density of grazing points in the whole study area ranged from 0 to 34 points/km^2, with an average of 5.2 points/km^2. There were 878 grazing points observed in the study area: 370 (42.1%) of them were in the southern sector (Table 6).

The large number of grazing points within this sector can be attributed not only to its location near cities and highways, but also to the availability of biomass and water within this area. Water is brought from many watering points in this area and the animal food market is a few kilometers away from these points. This study mapped all the watering points as shown in figure (2). It is clearly noted from figure (2) that grazing point distribution and watering points were highly related.

As indicated from the present survey, the livestock within the grazing points were mainly sheep or camels, while goats were less common. Both sheep and goats can be found within the same grazing point, while camels were separate with their own grazing points. Sheep and goats were both highly gregarious and generally incapable of moving large distances from water holes. Camels have certain advantages in the fight against desertification compared to sheep and goats. They produce more milk for longer periods, and continue to produce adequately throughout the dry season. Camels also have more varied diets, can travel further in a day (causing lower intensity of grazing and trampling around settlements), and are more efficient than sheep and goats in terms of vegetation consumed for quality of milk produced (Goudie, 1996). Furthermore, camels are less dependent on watering points (and so can exploit a much larger proportion of the available range).

The contour map of grazing points (Figure 6) showed another cluster in the North-Western sector near the border with Iraq. This can be attributed to the amount of feed available from *Haloxylon salicornicum* and *Cyperus conglomeratus* fields, which are now almost totally overgrazed. Furthermore, within 5 km of the border with Iraq, there is a security zone surrounded by a berm with a height of 2m where the plant cover inside is denser.

Recent field surveys indicated the use of at least three vehicle types comprising water tankers and two 4x4 wheel drive vehicles. There were more than 2634 vehicles (878 grazing points x 3 vehicles).

Table 6. Area and percentages of the study area grazing point densities.

Grazing point	Total area		Southern area		Mid area		Northern area	
density (unit/km^2)	(Km^2)	Total %	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
Very slight (<3)	1800	42	209	16	790	47	800	63
Slight (3-5)	1036	24	330	25	586	35	120	10
Moderate (5-10)	780	18	272	21	277	16	230	18
Severe (10-20)	539	13	392	30	31	2	115	9
Very severe(>20)	115	3	115	9	0	0	0	0
Total	4269	100	1318	100	1685	100	1266	100

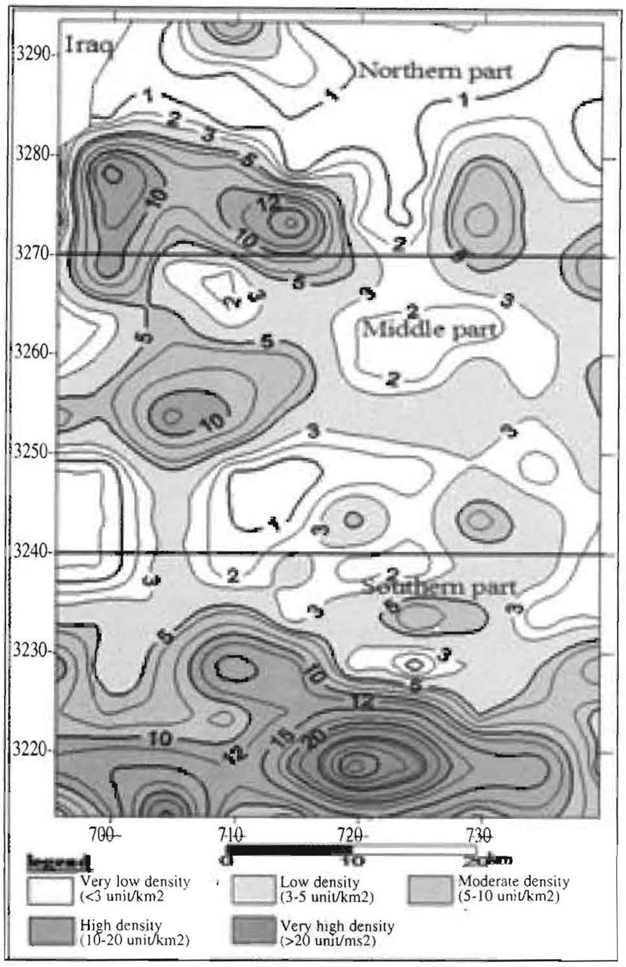

Fig. 6. Grazing points density map of the northwestern area of Kuwait

Through the use of these vehicles, grazing animals can travel farther into the desert. This can cause further degradation of natural vegetation and also lower the quality of the pasture and a loss of biodiversity. Most of the palatable species such as *Haloxylon salicornicum, Rhanterium epapposum and Stipagrostus plumosa* have been replaced by less palatable *Cyperus conglomeratus* and *Cornulaca leucacantha,* especially in the Southern area. Also, desert plants protect the surrounding sediments from the effect of crustation due to bombardment of rain droplets. Table (5) shows variation in infiltrated water, the depth of the wet zone and soil strength of non-compacted soils (natural) due to the effect of soil crustation indirectly resulting from the destruction of vegetation cover. The impact of human and livestock pressure is still more catastrophic on the vegetation cover. (Omar *et al.,* 2003) count vegetation in two sites within this study area, the first in a preserved area in Wadi Al-Batin in the Northern sector, and the second in the Southern sector. They found that vegetation is much denser in the preserved area (27.1% in comparison to 0.3% in the southern sector).

(III) Sandy Berms

The construction of sandy berms was mainly undertaken in the early years after the Second Gulf War (1990-1991). The total length of sandy berms (2m in height and 8-10m wide) in the study area is 428.8 km. The average width of the damaged soil on both sides of the berms is around 50m. So, the total damaged area along the berms covers 21440.000 m^2. The amount of excavated soil for constructing these berms was 4288 000 m^3 (i.e. 50,000 m^3km^{-1}). The change in total length of berms between 2002 and 1992 was small. The difference was mainly in the North-Western part of the study area around military camps and maneuver areas. Constructed berms mostly extend either from east to west or North to South and were concentrated mainly in the Southern and Middle areas. This kind of distribution of sandy berms can affect the hydrological balance of the area. They block the runoff water from flowing downstream. In this study we delineate all affected and non affected hydrological basins in all the three main sectors in the study area (Table 7). There are 208 hydrological basins within the study area, 77 basins (37% of the total basins in the area) were dissected by sandy berms. Consequently, a new pattern of hydrological basins was formed which led to severe damage to soil and vegetation.

Table 7. Magnitude distribution of sandy berms and gravel quarries, and its effect on hydrological basin within the three main sectors.

Area	Length of berms	Area occupied by quarries (km^2)	Number of wadis	Number of hydrological basins cut by berms	Number of hydrological basins affected by quarries	Total hydrological basins affected	% of wadis affected
Southern sector	230	0	100	46	0	46	46
Middle sector	98	8.75	59	11	2	13	22
Northern sector	101	86.25	49	20	15	35	71
Total	429	95	208	77	17	94	45

There were five main berms within the study area oriented almost at a right angle to the prevailing North Westerly wind (See figure 2). The total length of these oriented berms was 162 km. The Land use map (Figure 2) indicated six lines of berms through which the dunes pass. The sandy berms may have contributed in one way or another in increasing the number of dunes in the area. These sandy berms act as a sand barrier for the mobile sand (Figure 7). Different types of sand dunes have formed around the sandy berm at As-Suqayhiyah.

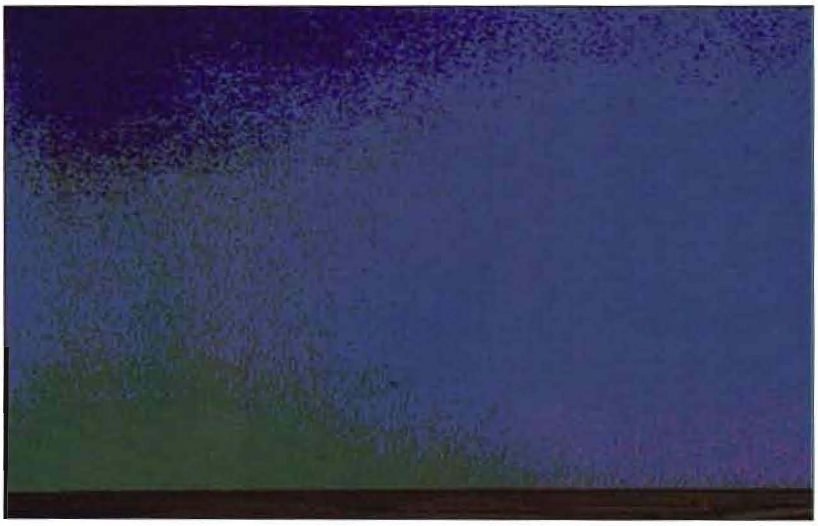

Fig. 7. Belt of sand dunes formed on a sandy berm in the North Western area of Kuwait.

(IV) Gravel Quarries

Gravel quarries were another form of disturbance distributed mostly in the Northern portion of the study area. They have been controlled by law in Kuwait including the study area since October 1997, but the enforcement was never applied until the middle of 2000. The total area of gravel quarries was 95 km^2, occupying 2.2% of the study area. The area given for each gravel company by the governmental permeation is (1) km^2. There were at least 95 quarrying companies in the study area. (10) persons and (3) heavy vehicles on average were observed through field survey around each quarry. Thus, there were 950 persons and 285 heavy vehicles working in gravel quarries within the study area. Quarry distribution patterns can be described as large and irregular. The quarrying began with small pits for exploration and testing the amount of gravel present. These testing pits were scattered around the quarries. Furthermore, the continuous sieving and transportation of gravel on heavy vehicles through the off-road areas have caused a lot of disturbance to the soil, leaving dusty clouds on the horizon that can be seen easily from Kuwait city in the early morning. In respect to Kuwait, there are about 400,000 tons yr^{-1} of dust lifted due to sand and gravel quarrying and mechanical transportation by heavy vehicles (Kuwait Environmental Protection Authority, 1997).

The Northern area is characterized by the abundance of five belts of gravel quarries. All tend to be in a North-Eastern direction, perpendicular to the dune corridor and prevailing wind direction. On the other hand, quarries mostly occupied the North-Eastern part of the study area. It is worth mentioning that the gravel quarrying also extended into the middle sub area but to a lesser extent than the Northern quarries.

The North-Eastern lying quarries were dominantly localized within three main gravelly sand ridges in the Northern and Middle areas. Furthermore, long parallel valleys run between these geomorphological ridges, separating them from each other. These valleys are generally occupied by sand dunes or other aeolian forms. The aeolian landforms were observed in the aerial photography of 1997 in the form of tongues of mobile sand connecting the gravel quarries and sand dunes. These tongues of mobile sand seemed to act as small mini-corridors and extended to various distances ranging from several hundreds of meters to a few kilometers downwind, feeding the sand dunes with sand. There were (54) sand dunes originated downwind of small quarries which acted as a source area for those dunes and were clearly seen in aerial photography from 1992. Also, it was observed that the dunes downwind of the gravel quarries tended to be smaller than the surrounding dunes, which may indicate a younger age.

The micro-relief of the Northern sector of the study area is highly affected. Also the hydrological balance was disturbed. Table 7 shows that 17 (8.2%) of the hydrological basins were affected by gravel quarries and a new pattern of basins was formed.

Conclusions and Recommendations

Socio-economic activities in North-Western Kuwait were represented by four main patterns: vehicle tracks, overgrazing, sandy berms and gravel quarries. All these activities were delineated in the form of statistical data and three different maps. The current data was also compared with other case studies in Kuwait. The present study showed that these activities were the major causes of land degradation. Indicators of land degradation were revealed through the deterioration of natural vegetation, loss of biodiversity, hydrological disruption, deterioration of the physical properties of soils and sand mobilization. The off-road tracks caused soil compaction and a decreasing of soil infiltration by 58% that led to changing the hydrological cycle of the area. There were (208) hydrological basins within the study area, (94) (i.e. 45%) of them were disturbed by sandy berms and gravel quarries. In addition, socio-economic activities resulted in the deterioration of vegetation cover which led to an increase in the intensity of mobile sand movement in the area. Sandy berms and gravel quarries had the greatest impact on dune formation and distribution. There were (1018) facilities within the area, (66%) of them (i.e. 673) were threatened by a sand encroachment problem. The deterioration that has occurred resulted in decreased livestock capacity and a loss of wildlife and changed micro-geomorphology, landscape and surface deformation of the study area. Comparison between some of socio-economic activities such as asphalt roads, sandy berms and density of off-road tracks in the study area with other case studies in Kuwait, showed that the off road track density within the study was about three times higher than other case studies (Table 8). Also, it was concluded that a high level of direct correlation between the off-road tracks and grazing point exists. The southern part of the study area was severely degraded and needs more enhancements in future planning in comparison to the Northern and Middle parts.

Discussions with livestock owners indicated that they had several problems represented mostly by the economic cost of feeding their livestock. Other problems were presented by fencing and the protecting of rangeland for different purposes, including oil fields, military areas or border areas. Legislation protects parts of the rangelands through fencing, without giving the livestock owners other acceptable choices. Such legislation considers that grazing by domestic livestock may lead to environmental set backs, without taking into consideration the concept of rangeland management, of which livestock and rangelands are elements complementing each other.

It is highly recommended to initiate control measures for the limitation of land degradation in this pilot study. Fencing of highly degraded sectors within the study area is also recommended. More control should be considered on watering points in future planning for the limitation of overgrazing. The management concept of rangelands that takes in considering livestock and rangelands as elements complementing each other should be used. The key to any successful rangelands management program is law, enforcement and regulations. A good example in Kuwait is law (number 41 of 1988), decisions number (242, 243) and (244 of 1989), and (110 of 1999) for range management control. In addition, see the United Nation Agreement law number (134 of 1997) concerning the UN Agreement on Convention of Combating Desertification and land degradation (UNCCD). Also Long term environmental monitoring of natural vegetation, soil and wildlife should be conducted. Considerable efforts should be made to ensure realistic and sustainable use of the resources through establishing scientific research activities to quantify and qualify livestock and rangelands in order to build up a reference database. Also research is needed to evaluate the required food supply and water quality for grazing animals for both the present and future.

Off-road vehicles need to be restricted to fewer tracks. Shallow ploughing for the highly compacted soils caused by off-road vehicles can be suggested before the rainy season (October-April). Moreover, the gravel quarries need long term rehabilitation plans beginning with the leveling of pits and sandy piles during the winter time resulting from exploitation stage. As a result of the berms effect on the hydrological cycle of the area, outlets on the berms should be considered to lead the natural flow

Table 8. Densities of asphaltic roads, sandy berms and off-road tracks within the study area in comparison to other case studies in Kuwait.

Location	Area (km^2)	Asphalted roads		Sandy berms		Off-road tracks (km/km2)	
		Total length (km)	Density/ km^2	Total length (km)	Density/ km^2	Range	Average
Study area	4269	184	0.04	428.8	0.1	0.46-4.27	2.49
Al-Salmi*	1345	28	0.02	102	0.08	063-1.02	0.81
Al-Mutlaa**	736	50	0.07	30	0.04	0.53-1.4	0.89

* Al-Dousari et al. (2000) ** measured from map in Misak et al. (2000)

of hydrological basins. The mobile sand movement should be stabilized through applying sufficient control measures.

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