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ORIGINAL ARTICLE

Off-Road Vehicle Tracks and Grazing Points in Relation to Soil Compaction and Land Degradation

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Abstract

The land degradation in Kuwait presents into two main forms, namely, soil compaction and loss to native plants. These two forms of land degradation are highly related to off-road vehicle tracks and grazing points. Therefore, the off-road vehicle tracks and grazing points were delineated for the first time within all Kuwait using Worldview and Rapid Eye images 2017 and ArcGIS. There is 871,811 grazing livestock (sheep, goats, and camels) spread into 2473 grazing points was detected in Kuwait open desert in 2017. There are around 354 as average livestock in each grazing point. The total length for off-road vehicle tracks is 14,774.7 km spread over Kuwait which is equivalent to 1.16 times more than the length of the planet earth mean diameter. The off-road vehicle tracks and grazing points are a leading cause for land degradation and soil compaction in Kuwait. Aeolian activities were monitored for 1 year at downwind of an off-road vehicle track at 10 m, 50 m, and 200 m. The results show more quantities of mobile sand, and dust was trapped at 10 and 50 m compared with the 200 m distance from off-road vehicle track. Consequently, the total area affected by soil compaction due to off-road vehicle tracks and grazing points in Kuwait is 1390.23 km^2 representing 7.8% of the total area of Kuwait. It is concluded that grazing points and off-road vehicle tracks are highly related to each other, and both are jumped to higher densities around the urban area and watering points. As a result, it is strongly recommended to develop a national action plan to control off-road vehicle tracks and grazing points by putting into practice a proper rangeland management plan in Kuwait. Steps of the action plan were outlined for this study.

Keywords Land degradation · Soil · Compaction · Off-road vehicle tracks · Overgrazing · Aeolian · Kuwait

1 Introduction

UNEP accepted defining land degradation as loss or reduction of the economic or biological return of land results due to different factors counting climatic variations and human activities (Okuro 2010). Land degradation used to be concerned with changes in soil's physical, chemical, and biological properties (FAO 2018). Under the environmental conditions of Kuwait, land degradation is exacerbated by the scarcity of rainfall and intensive wind and water erosion (Al-Awadhi and Al-Dousari 2013).

Native plants can provide a shielding boundary or cover between soil and atmosphere (Al-Awadhi et al. 2014; Ahmed et al. 2015). The plant species in the Kuwaiti desert can be classified either as annual or perennial. There are 374 plant species in Kuwait, 256 are categorized as annual, while the rest (118) are perennial (Boulos and Al-Dosari 1994). The latest Kuwait vegetation map was done by Omar et al. (2001) identifying eight major vegetation units. *Haloxylon salicornicum* as one of the dominant plant communities in Kuwait is characterized by a big crown which protects the soil from crustation due to rain droplets bombardment. However, *H. salicornicum* has been exposed to severe demolition by overgrazing and off-road transport. The deterioration of native plants will cause an increase in aeolian activities and surface runoff (Al-Awadhi et al 2000; Al-Dousari et al. 2008).

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In Kuwait, field surveys confirm that the native plants cover plays a key role in prevention of soil crustation (Al-Dousari et al 2000). However, the existing natural plant species have been subjected to damage by a wide variety of activities (Al-Dousari and Al-Hazza 2013). Kirby et al. (1997) noticed that with the increasing passage of tires over soil from the first pass to the eighth pass, the void spaces were considerably decreased. 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 off-road traffic can change the physical properties of the soil in a way that may lead to decrease in infiltration capacity in the off-road vehicle tracks, increased risk of surface runoff, and insufficient aeration for optimal seedling growth (Hansson et al. 2018). The infiltration capacity of the compacted soils has decreased by 35% compared to non-compacted soils in western Kuwait (Al-Dousari et al. 2000). Subsequently, soil compaction and surface sealing increase runoff erosion. Johnson et al. (1979) claimed that the formation of a surface seal and soil compaction reduces sheet and rill erosion rate and, subsequently, soil infiltration. Vehicles that are traveling off-road can cause wind erosion and vehicle dust emissions to cause adverse effects on respiratory health and contribute to degradation for air quality and land (Retta et al. 2014). It has been widely affirmed that high grazing stress has led to a reduction in vegetation density at decadal time scales hinted at land degradation (Rasmussen et al. 2018). Off-road vehicles, tracks are considered a leading cause of land degradation in arid and semi-arid regions (Assaeed et al. 2018). Assaeed et al. (2018) observed the vegetation reacted negatively to distance away from off-road tracks.

In general, the total number of grazing livestock in Kuwait is higher than the grazing capacity of the land in Kuwait (Al-Dousari 2005). Grazing rangeland as a dominant land-use type is representing 72.3% of the total land use in Kuwait (Omar et al. 2001). Misak et al. (2007) revealed that thousands of grazing livestock in Kuwait are concentrated everywhere around the watering points, which are sporadically spread throughout the desert. Overgrazing around watering points in arid and semi-arid areas can also increase sand deflation (Goudie and Thomas 1985). Overgrazing is widely regarded as a prime cause of desertification (Goudie 1996). If grazing management on arid and semi-arid lands is inappropriate, then land degradation can occur (Tueller 1998). The high soil's albedo denuded by overgrazing, and off-road tracks may result in a reduced lifting of required air for precipitation and cloud formation and thus lead to regional climatic consequences (Otterman 1974).

In Kuwait, there is around 5.82 million tons of average annual deposited dust in Kuwait (Al-Dousari et al. 2019); 400,000 tons from these amounts are lifted due to gravel and sand quarrying and mechanical transportation for heavy vehicles in off-road tracks (KEPA 1997). Therefore, the aim of this study is to delineate and quantify the off-road vehicle tracks and grazing points in Kuwait and their effect on aeolian activity.

2 Study Area

Kuwait is at the north-western corner of the Arabian Gulf bordered by Iraq on the northwest and by Saudi Arabia on the south. The land surface within the study area is composed of clastic sediments regionally known as the Kuwait Group. The Kuwait Group (Miocene-to-Pleistocene) is composed of sand with gravel, minor clay, calcretic, and gypsiferous sandy clay beds (Khalaf et al. 1995; Ahmed and Al-Dousari 2013).

Kuwait has a hot and dry climate with a 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 temperature was 52 °C in July 2015, while the lowest temperature was 6 °C in January 1964 (Al-Dousari et al. 2017). Rainfall is erratic and scanty with 112.1 mm/year (1962–2017) as average annual. The wind blows from two main directions: dominantly from the northwest and from the southeast in a lesser extent.

The grazing points are the shelter for the grazing livestock and they are sporadically distributed in the Kuwaiti desert. This kind of distribution causes dense off-vehicle tracks all over Kuwait. There are some governmental supports for the livestock owners by animal feeds, but it is not enough; therefore, native plants in the desert are suffering.

3 Methodology

This study uses five steps to meet the objectives, namely;

1. A set of images from WorldView 2017 (30 cm resolution, bands 5, 3, 2), Rapid Eye 2017 (5 m resolution, bands 4, 3, 2) were used to delineate all off-road vehicle tracks and grazing points in Kuwait. The all off-road vehicle tracks (above 3 m width) and grazing points were digitized using ArcGIS for image service ESRI software that allows high special resolution for the study area. Kuwait was divided into 31 sub-areas each with 30 km^2 (Fig. 1a). The lengths of off-road vehicle tracks, as well as grazing point densities, were measured and counted, respectively, for each square kilometer of all the 31 sub-areas. In this study, a 1 km^2 grid system is used to address data to a high level of accuracy. Data were presented on two maps, namely; the off-road vehicle track and grazing point's density maps and superimposed into the soil, vegetation, and hydrological maps

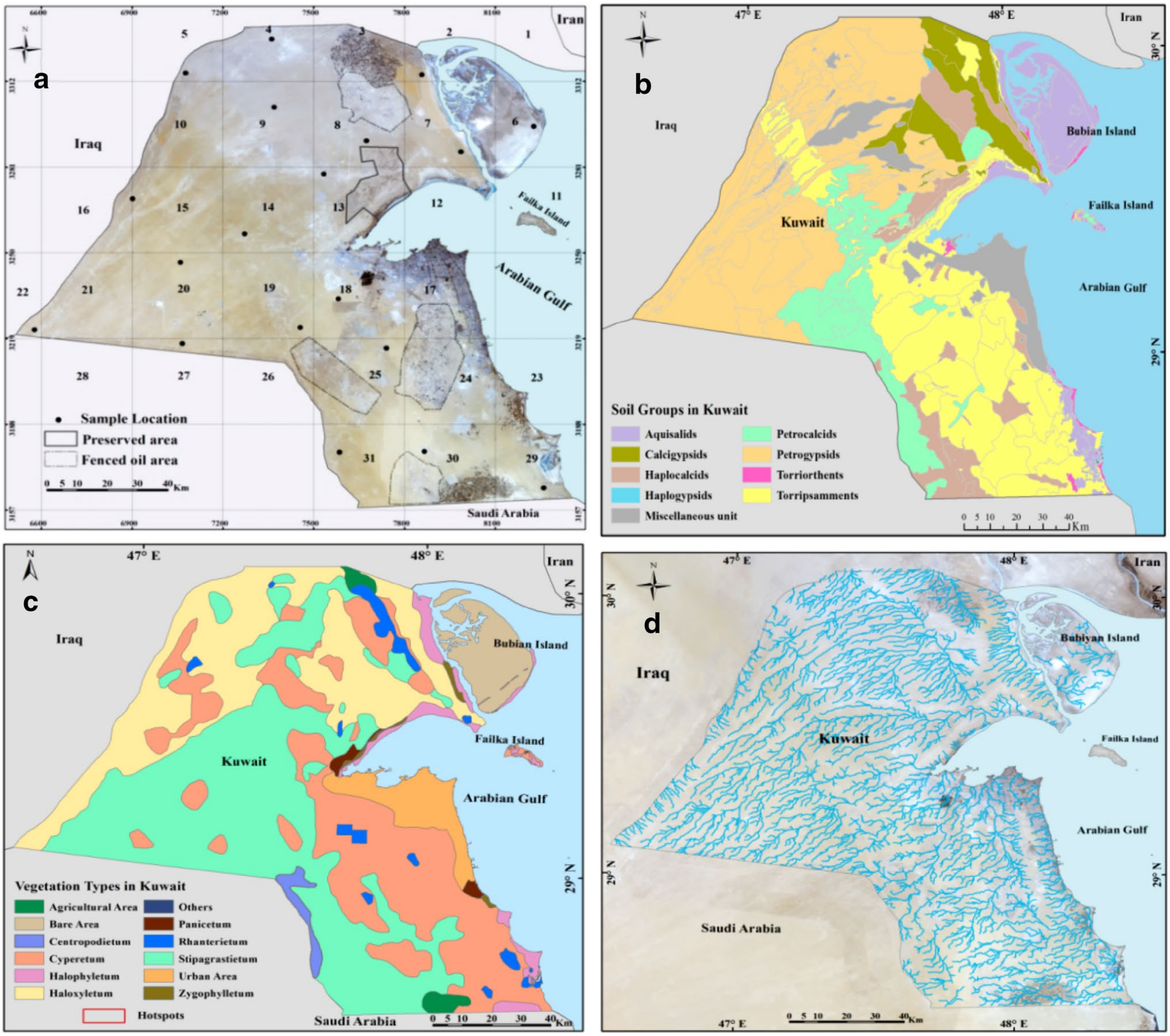

Fig. 1 Kuwait with 31 sub-areas and sampling sites (**a**), soil and vegetation (Omar et al. 2000) maps (**b**, **c**), and drainage system map (**d**)

for Kuwait (Fig. 1b–d). The grazing points have been identified via satellite images mentioned above and field observation based on three main characteristics:

a) High albedo due to the absence of vegetation cover in the grazing points with a darker tone at the center resulted in livestock organic matter.
b) Dense off-road vehicle tracks spread from the grazing point.
c) Presence of tents, metal fences, and sometimes water tanks.

2. In addition, multiple aerial photos were captured during several field visits and helicopter trips (Fig. 2a) for the count of the average livestock and vehicles (Fig. 2b, c) around 40 grazing points during the livestock (Fig. 2d) gathering time (at sunset and/or sunrise) to reach to the average density for single grazing point.
3. A total of 50 shallow soil profiles from 19 locations were carefully chosen covering all geological formations (4 formations), soil classes (9 classes), and vegetation types (8 major types) in Kuwait from non-disturbed and disturbed soil by off-road vehicle tracks. The bulk density was measured by the USDA method (USDA 1996) and porosity was calculated for all samples. Infiltration tests in seven different sites for each location were conducted using the double-ring method with 15 cm and 30 cm diameter for inner and outer rings, respectively.

Fig. 2 Aerial photos were captured using helicopter trips (**a**) for off-road vehicle tracks (**b**, **c**) and grazing point (**d**), traps for monitoring aeolian sand (**e**) and dust (**f**)

In each site, two tests were carried out: one in the compacted soil by off-road vehicle tracks and the second in the non-compacted (natural). The duration of each test was 30 min, where the height of the infiltrating water was measured at regular time intervals in all tests. The depth of the infiltrating water from the soil (wet zone) was also measured in a shallow pit dug for this purpose. The compressive soil strength was measured using hand penetrometer.

4. To monitor aeolian deposits caused by off-road tracks, a main off-road was chosen with 18.2 m width located upwind of a preserved area. In this study, aeolian activities (mobile sand and deposited dust) were monitored using sand and dust traps at 10 m, 50 m, and 200 m

downwind of this off-road track for one 12 months from September to August. In addition, a sand and dust traps were fixed at a control area located at 200 upwind of the main off-road vehicle. The dust and sand traps were contrived at KISR following the design of Reheis (1995) after modification by Al-Dousari and Al-Awadhi (2012) and Al-Awadhi et al. (2014), respectively. The sand trap is unidirectional, with 1 m height from the ground level and 1 cm aperture fronting the foremost wind direction (N45W). The dust trap was manufactured with a 240 cm height from the ground level and 20 cm radius (Fig. 2e, f).

5. Information about the grazing livestock types (sheep-camels and goats) and counts was obtained from the official site in Kuwait (MOP 2018) and compared to neighbouring countries (FAO 2018).

4 Results and Discussion

The population density in Kuwait increases from 2 persons/km^2 in 1910 to 229.1 persons/km^2 in 2017 (Table 1). The total number of vehicles in the country in 1989 was 622,311 vehicles, which is 34.9 vehicles/km^2, while it was 116.7 vehicles/km^2 in 2017.

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

Table 1 Population and vehicle densities in Kuwait (1910–2017) (MOP 2018)

Year	Population	Density (km^2)	Vehicles	Density (km^2)
1910	35,636	2.0	0.0	0.0
1989	2,054,578	115.3	622,311	34.9
1995	1,575,570	88.4	816,471	45.8
1997	1,809,270	101.5	654,667	36.7
2000	2,138,115	120.0	801,555	45.0
2001	2,182,609	122.5	941,091	52.8
2002	2,261,956	126.9	907,221	50.9
2007	3,328,136	186.8	1,210,000	67.9
2011	3,065,850	172.1	1,554,737	87.3
2012	3,246,622	182.2	1,644,314	92.3
2013	3,427,595	192.4	1,784,424	100.1
2014	3,588,092	201.4	1,837,372	103.1
2015	3,743,660	210.1	1,925,168	108.0
2016	3,925,487	220.3	2,001,940	112.4
2017	4,082,704	229.1	2,078,712	116.7

4.1 Off-Road Vehicle Tracks

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

1. Very severe off-road vehicle tracks (> 1.0 km/km^2).
2. Severe off-road vehicle tracks (0.8–1.0 km/km^2).
3. Moderate off-road vehicle tracks (0.6–0.8 km/km^2).
4. Slight off-road vehicle tracks (< 0.6 km/km^2).

The severe and very severe off-road vehicle tracks prevail in western and south-eastern areas of Kuwait, while the moderate class was dominant in the southern areas. The northern area shows the highest percentages of slight and very slight off-road vehicle tracks. The density of off-road vehicles ranged widely from 0.43 to 2.10 km/km^2 with an average of 0.92 km/km^2. The high density of off-road tracks in some segments was attributed to the intensive military as well as civilian activities; for instance; the extreme southern segment of the area has the highest density of off-road tracks (4.27 km/km^2), indicating very extensive human activities, in the southern part of the study area.

The off-road vehicle tracks (Fig. 4) cut most of the wadis, causing an imbalance in the hydrological cycle of the area. On the other hand, grooves, ruts, and scars produced by vehicle's traffic to have disturbed the micro spread system of runoff. Consequently, a new pattern of minor hydrographic basins was developed. This has caused severe damage to soil and vegetation. The vegetation reacted negatively to distance away from off-road tracks (Assaeed et al. 2018).

The total length for off-road vehicle tracks in Kuwait is 14,774.7 km with a 37.4 m average width (Fig. 3). The total length for off-road vehicle tracks is equivalent to 1.16 times more than the planet earth average diameter. Such causes enormous pressure on wildlife and the environment in Kuwait. The off-road traffic can change the physical properties of the soil by decreasing the infiltration capacity, which cause insufficient aeration for optimal seedling growth, changing the area micro-drainage system and increased risk of surface runoff (Hansson et al. 2018). The natural and compacted soil shows high variation in average infiltrated water and water depth by 67% and 43%, respectively (Table 2). The off-road tracks affect intensively most of the plant communities in Kuwait, majorly Stipagrastietum, Cyperetum, and Haloxyletum by 47.3%, 24.9%, and 18.7%, respectively (Table 3).

Aeolian activities were monitored for 1 year at downwind of an off-road vehicle track at 10 m, 50 m, and 200 m. The results show more quantities of mobile sand, and dust was trapped at 10 and 50 m compared to the 200 m distance from off-road vehicle track. The annual aeolian accumulations show high intensity around 10 m and 50 m downwind of the main road track, but there is no effect noted after 200 m. The

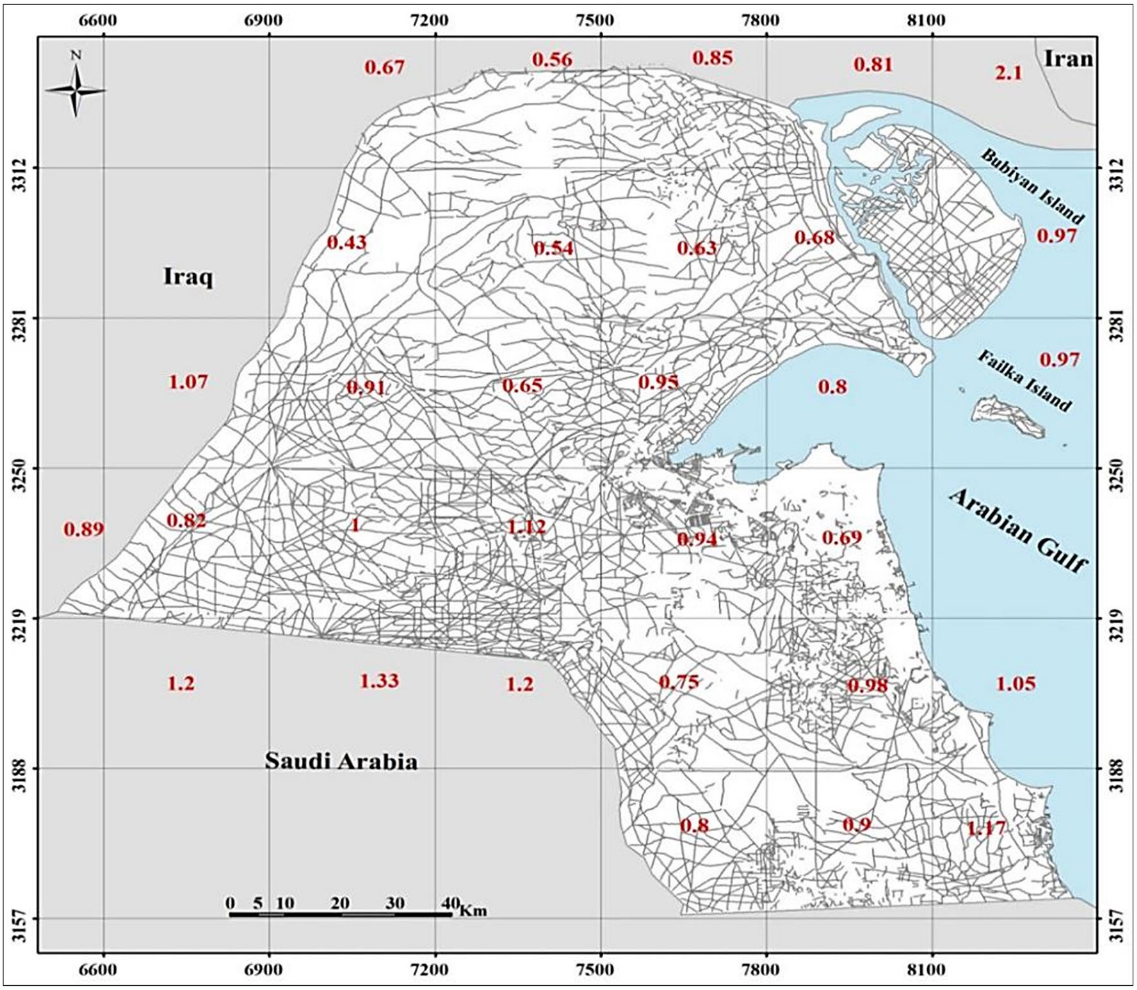

Fig. 3 Off-road vehicle tracks map showing the density in km/km^2 for all the 31 sub-areas in Kuwait 2017

Table 2 Differences in the average volume of infiltrated water, depth of wet zone, and soil strength

Stat	Average volume of infiltrated water (cm^3 min^{-1})		Difference (%)	Depth of wet zone (cm)		Difference (%)	Soil strength + (kg cm^{-2})		Difference (%)
	Natural	Compacted		Natural	Compacted		Natural	Compacted	
Mean	178.24	31.91	69.63	30.79	12.36	42.72	6.29	6.42	0.03
SD	176.13	15.30	84.01	14.44	7.29	32.90	2.44	2.44	0.00
Max	436.19	57.11	76.85	54.00	24.00	38.46	8.50	8.50	0.00
Min	23.18	13.57	26.15	14.00	3.00	64.71	2.00	2.10	0.10

annual sand accumulations in sand traps at 10 m and 50 m increase by 99.2% and 64.4% compared with 200 m downwind of the off-road vehicle track (Fig. 4a). The trapped sand quantities show the highest values in September, October, and November (Fig. 4b) that could be related to camping period and neighboring grazing points. On the other hand, deposited dust in dust traps at 10 m and 50 m increases by 67.4% and 36.7% compared to 200 m downwind of the off-road vehicle track (Fig. 5a). After comparing data from all traps with a control area, deposited dust is active during October until January (Fig. 5b). Using multiple radionuclides as a tracer, it was found that most of the dust collected from dust traps in Kuwait is resulted from re-suspended after the first deposition (Aba et al. 2016, 2018). The re-movement of dust particles after the first deposition in Kuwait can be attributed to anthropogenic activities including off-road

Table 3 Percentages of vegetation and soil types affected by grazing points and off-road tracks

	Grazing point (%)	Off-road tracks (%)
Plant type		
Stipagrastietum	47.34	48.25
Cyperetum	28.82	24.92
Haloxyletum	14.82	18.71
Halophyletum	3.21	2.91
Rhanterium	1.32	1.86
Centropodietum	1.28	1.39
Panicetum	1.40	0.64
Agricultural area	1.81	1.32
Soil type		
Petrogypsids	30.50	30.30
Torripsamments	29.30	27.50
Petrocalcids	24.18	17.70
Haplocalcids	7.90	9.70
Calcigypsids	5.52	6.20
Aquisalids	1.94	8
Torriorthents	0.66	0.53
Haplogypsids	0	0.07

vehicle tracks (Al-Dousari 2009). The effect of off-road tracks appears in the physical properties of aeolian particles (Blott et al. 2004). The increase in Aeolian activities causes a severe socio-economic effect on Kuwait and surrounding areas (Al-Hemoud et al. 2018).

4.2 Overgrazing

Through the current field survey, average livestock in the study area was found 50 livestock/grazing point. There is 871,811 grazing livestock (sheep, goats, and camels) spread into 2735 grazing points which was detected in Kuwait open desert in 2017. There is around 354 average livestock in each grazing point which is convenient with the total number of livestock in relation to total number of grazing points within Kuwait (Table 4). Therefore, Kuwait is located within the top five Arab world countries in grazing livestock densities. The total number of livestock, including sheep, goats, camels, and cows in Kuwait during 1980 was 447,781 with a density of 25.13 livestock per square kilometer, in which sheep and goats represent 94.3% (Table 4). In the years 2000, 2016, and 2017, a tremendous increase in livestock was observed had taken place in comparison to 1980 to 694,553; 878,983; and 871,811, respectively. Sheep and goats represent 99.3%, 98.7%, and 98.9% of the total livestock in Kuwait in 2001, 2016, and 2017, respectively (Table 5).

Grazing points varied in shape and distribution. They were classified according to size and shape into isolated or compound. The remote grazing points were small in size, mostly serving camel livestock and dominantly concentrated on the border areas with Iraq. On the other hand, compound grazing points encompassed with two or more grazing points close to each other. They are larger in size, bare of any vegetation and predominantly serving goats and sheep. The compound grazing points' average diameter increased with an increase in the number of grazing points. Through the field survey, the average area of a single grazing point is around 200 m^2 (Fig. 6).

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

1. Very high density (> 20 unit/km^{-2}).
2. High density (15–20 unit/km^2).
3. Moderate density (10–15 unit/km^2).
4. Low density (< 10 unit/km^2).
5. Density (unit/total area of Kuwait in km^2).

The density of grazing points in Kuwait ranged from 0.04 to 0.38 points/km^2 with an average of 0.15 points/km^2. There were 2473 grazing points observed within the study area mainly concentrated in the western and south-eastern sectors of the study area. A large number of grazing points within these sectors can be attributed to being close to the cities and the highway but also to the availability of biomass and water within this area as preferred by livestock owners. Watering points and animal feed market are close to the western and south-eastern sectors.

The livestock within the grazing points were mainly camels or sheep, while goats were less common. Both goats and sheep 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 a longer period and continue to produce adequately throughout the dry season. Camels also have more varied diets, can travel further in a day (causing the lower intensity of grazing and trampling around settlements), and were more efficient than sheep and goats in terms of vegetation consumed for the 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).

Overgrazing has become very acute in Kuwait in the past 20 years. Previously, the Bedouins maintained a delicate balance between the number of their grazing animals and the carrying capacity of the pasture. Furthermore, they did not use vehicles at all. Recently, this balance has been totally disturbed, not only due to the recent control of epidemic diseases and the increase in the animal population but also to the dramatic changes of the Bedouin's lives. These

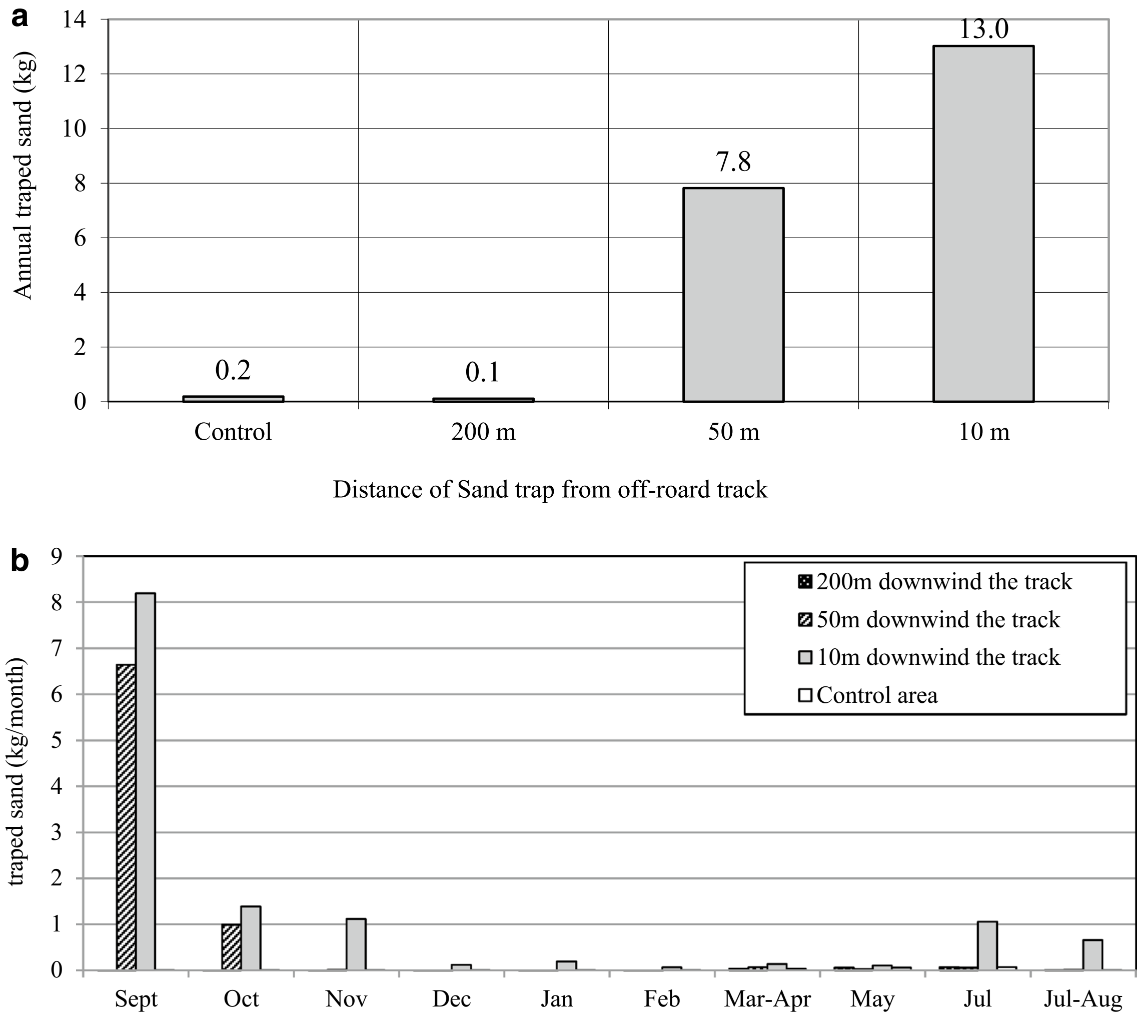

Fig. 4 The annual (**a**) and the monthly (**b**) aeolian trapped sand observed in sand traps at 10 m, 50 m, and 200 m downwind off-road vehicle track compared to control area for 12 months (September–August)

changes were noted by field survey that there are for each grazing point at least two vehicles comprising water tanker and pick up vehicles. There were more than 1,743,622 vehicles (871,811 grazing points multiplied by two vehicles). Through the use of these vehicles, grazing animals can travel farther into the desert. This can cause further degradation of natural vegetation and also a lower quality of the pasture and loss of biodiversity. Most of the palatable species such as *H. salicornicum*, *Rhanterium epapposum, and Stipagrostis plumosa* have been replaced by less palatable *Cyperus conglomeratus* and *Cornulaca leucacantha*, especially in the southern area. The impact of human and livestock pressure is still more catastrophic on the vegetation cover. Overgrazing has inadvertently been made worse, particularly in the southern areas, by drilling of additional wells to provide drinking water for livestock throughout the year. Overgrazing, particularly by sheep, has removed most of the perennial vegetation from open or non-preserved areas.

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 protecting of rangeland for different purposes, including oil fields, military areas, or border areas. Legislations protect 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 an environmental setback without considering the concept of rangelands management of which livestock and rangelands are elements complementing each other.

5 Recommended Action Plan

There are no much research and management policies which have made towards controlling and restoring the affected areas in Kuwait by off-road vehicle tracks and grazing points

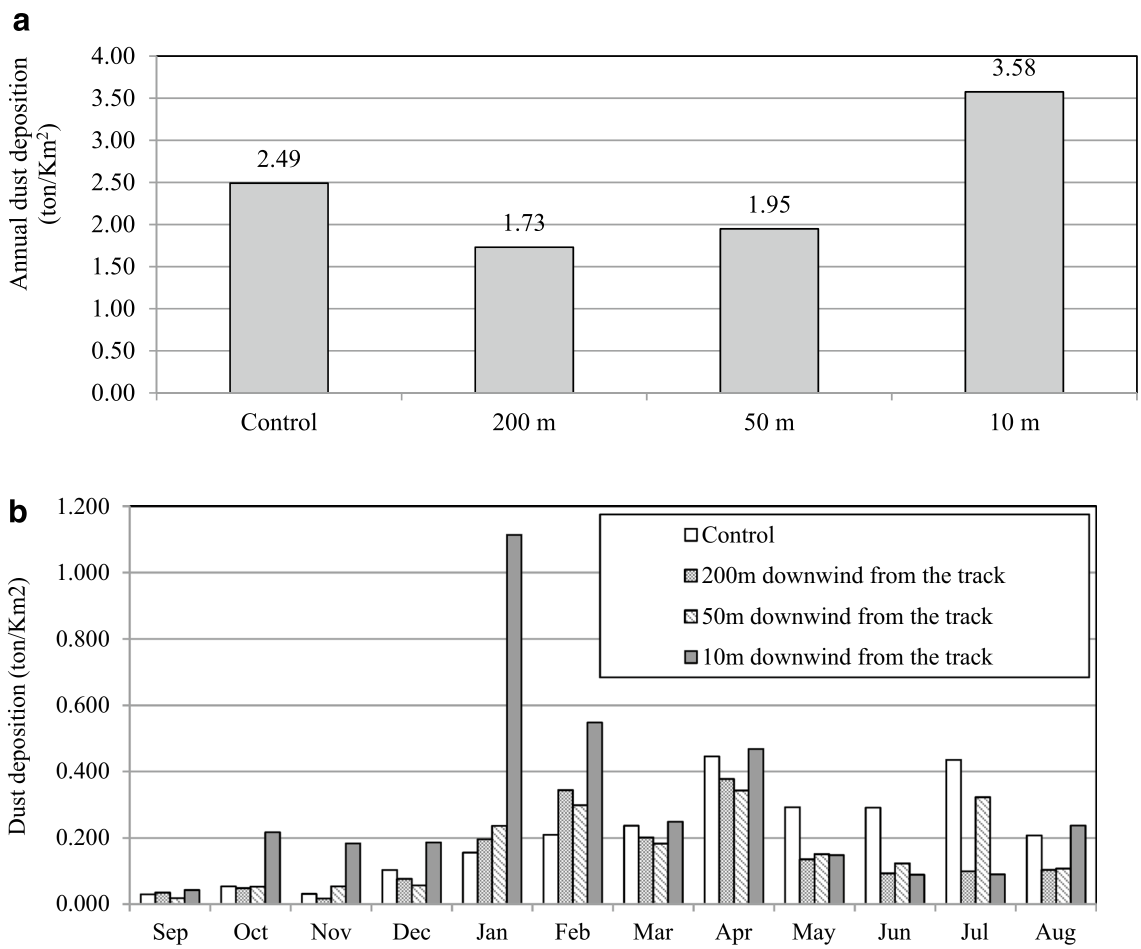

Fig. 5 The annual (**a**) and the monthly (**b**) aeolian trapped dust observed in dust traps at 10 m, 50 m, and 200 m downwind of off-road vehicle track compared to control area for 12 months (September–August)

and maintaining ecosystem function in desert areas. There is an immediate and long-term effect for grazing points and off-road tracks (Table 6). Gelbard and Harrison (2003) proposed reducing vehicle disturbances on tracks to maintain local biodiversity in arid regions. The northern parts of Kuwait show lower effect percentages by off-road or grazing point if compared to other areas. Therefore, we should keep it safe as any more disturbances will cause severe aeolian activities in Kuwait.

It is highly recommended to implement adaptation methods for the limitation of land degradation in the pilot study. More control should be considered on a distribution plan for watering points in future planning for limitation of grazing points. The management concept of rangelands that take considers livestock rangelands as element complementing each other should be used. The key to any effective rangeland management program is laws, enforcement, and regulations. In addition, long-term environmental monitoring of soil, natural vegetation, and wildlife should be accompanied. Moreover, off-road vehicles need to be restricted within a few major tracks. Shallow plowing for the highly compacted soils caused by off-road vehicles is suggested before the rain season (October–April). Considerable efforts should be made to ensure sustainable and realistic use of the resources through establishing scientific research activities to qualify and quantify livestock and rangelands to build up a reference database. In addition, research is needed to evaluate the required food supply and water quality for grazing animals at present and in the future.

6 Conclusions and Recommendations

Off-road vehicle tracks and grazing points are considered as main contributors to land degradation in Kuwait and the surrounding regions. Decades of intensive off-road vehicle tracks were formed in Kuwait due to anthropogenic activities such as grazing points, camping (November until March), border security, war activities (1990–1991 and 2003), military maneuvers, and hunting have prompted concerns about

Table 4 Grazing livestock counts and densities in Kuwait (MOP 2018) and neighboring countries (FAO 2018)

Country	Camels	Sheep	Goats	Counts all	Density (unit km^{-2})
Kuwait	9389	664,654	197,768	871,811	48.9
Saudi	248,205	11,007,972	2,596,799	13,852,976	6.4
Emirates	436,800	2,227,400	2,254,700	4,918,900	58.8
Bahrain	1073	39,209	17,991	58,273	0.1
Qatar	59,510	722,179	357,574	1,139,263	98.5
Oman	245,907	573,045	2,212,196	3,031,148	9.8
Yemen	479,914	10,211,412	9,156,000	19,847,326	37.6
Iraq	72,408	6,604,185	1,260,481	7,937,074	18.2
Syria	69,552	17,919,322	2,495,961	20,484,835	110.6
Jordan	14,610	3,198,925	977,755	4,191,290	46.9
Lebanon	202	450,805	516,014	967,021	92.5
Palestine		744,845	158,726	903,571	33.5
Egypt	141,965	5,639,551	4,118,917	9,900,433	9.9
Libya	62,125	7,330,817	2,645,240	10,038,182	5.7
Tunisia	237,114	6,406,100	1,184,600	7,827,814	47.8
Algeria	379,094	28,135,986	4,934,701	33,449,781	14.0
Morocco	58,000	19,870,000	5,600,000	25,528,000	35.9
Mauritania	1,483,210	9,600,982	6,207,476	17,291,668	16.8
Sudan	4,826,059	40,552,860	31,325,105	76,704,024	41.1
Somalia	7,221,998	11,771,916	11,692,227	30,686,141	48.1
Djibouti	70,996	469,076	514,408	1,054,480	45.5
Average	805,878	8,764,731	4,304,204	13,836,438	39

Table 5 Animal counts and stocking density in 1980, 2001, 2016, and 2017 in Kuwait rangelands (MOP 2018)

Livestock type	1980		2001		2016		2017	
	Unit	Density	Unit	Density	Unit	Density	Unit	Density
Sheep	396,870	22.3	521,408	29.26	695,699	39.0	664,654	37.3
Goats	25,180	1.4	168,173	9.44	172,259	9.7	197,768	11.1
Camels	25,276	1.4	4,972	0.28	11,025	0.6	9,389	0.5
Total	447,326	25.1	694,553	39.0	878,983	49.3	871,811	48.9

short- and long-term human effects on desert ecosystems. To help decision-makers identify areas vulnerable to soil compaction from anthropogenic activities, off-road vehicle tracks, and grazing point's density maps was developed. The off-road vehicle tracks and grazing point's density maps can provide valuable information on areas vulnerable to soil compaction resulted due to human activities and are detailed enough for adaptive management and restoration planning. The study emphasizes that managing grazing and off-road vehicle driving is essential for conserving native vegetation.

Consequently, the total area affected by soil compaction and degradation due to off-road vehicle tracks and grazing points in Kuwait is 1390.23 km^2 representing 7.8% of the total area of Kuwait. It is concluded that grazing points and off-road vehicle tracks are highly related to each other, and both are jumped to higher densities around an urban area and watering points. As a result, it is strongly recommended to develop a national action plan for controlling land degradation.

The present study showed that the socio-economic activities were the major causes of soil compaction in Kuwait. Thus, the future development strategies should include controlling the off-road driving tracks and grazing point's distribution in the open desert. In addition, these activities led to the degradation of native vegetation, loss of biodiversity, and lower quality of posture. Furthermore, the actions of man were effective in the processes responsible for increasing aeolian activities (dust and mobile sand intensity) in the study area. The deterioration that has occurred resulting in the loss of wildlife decreased livestock capacity and changed the geomorphology and landscape of the study area. Removal of vegetation and expansion of off-road vehicle activities were conducive to the conclusion that human effect was the most effective force modeling the area.

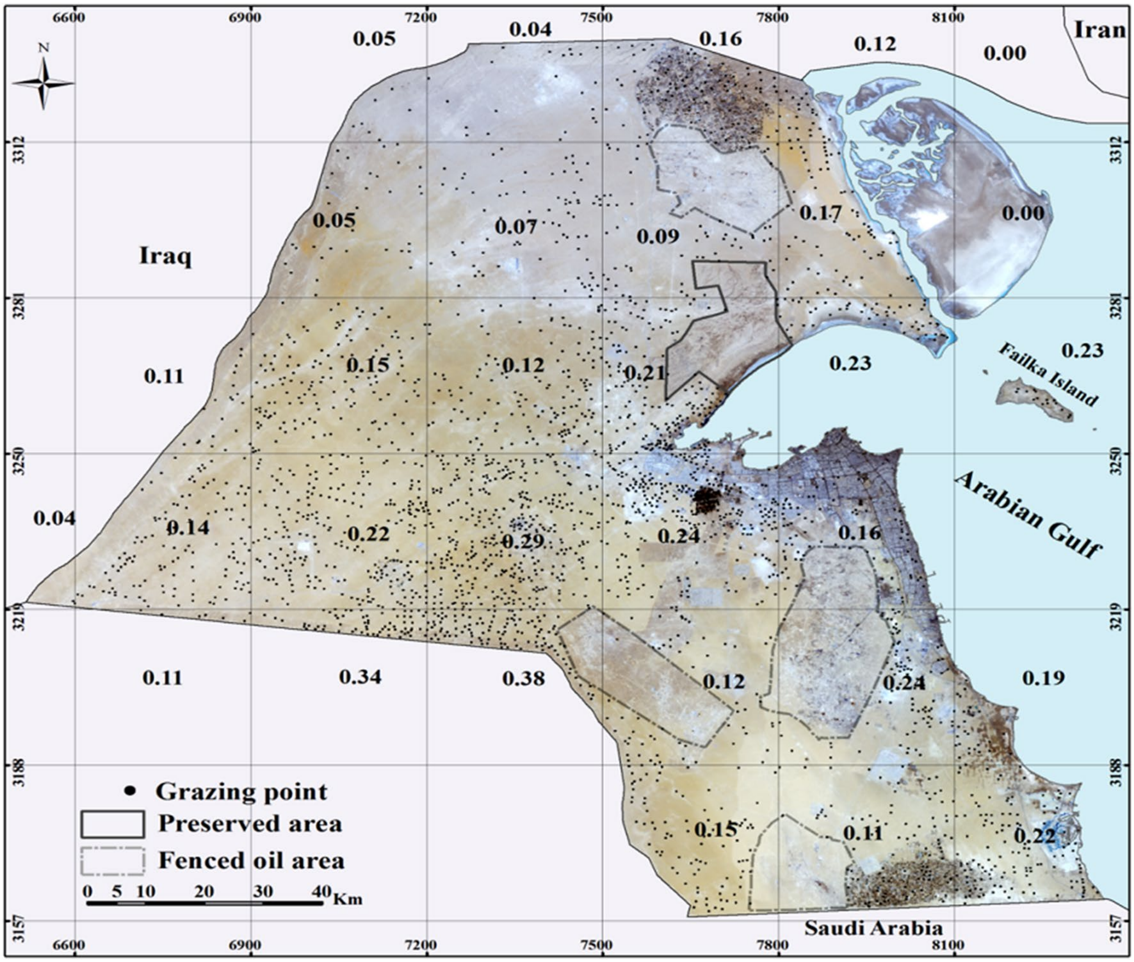

Fig. 6 Grazing points map showing the density in point/km^2 for all the 31 sub-areas in Kuwait 2017

Table 6 Land-use immediate and long-term impacts for off-road vehicle tracks and grazing points

Practice	Immediate impact (on-site effect)	Long-term impact (off-site effect)
Off-road tracks	Native vegetation deterioration	Soil fertility loss
	Soil compaction and a decrease of permeability	Development of sand drift and active mobile sand
	Exposure of the fine sediments to wind erosion	Increase in rate of water erosion (as a result of soil compaction and reduction in vegetation cover)
	Breaking of the armor layer of pebbles and gravels	Affecting the hydrological cycle
Grazing points	Depletion of the biomass and forage loss	Increase aeolian activities (dust and mobile sand) blowing in windy seasons
	Exposure of fine sediments (e.g. sediments within Phytogenic/coppice/nabkha dunes)	Expansion of creeping sand
		Increase the rate of wind and
		water erosion
		Decrease rate of soil recharge and dryness of vegetation cover
		Cause of high albedo (which may decrease the lifting necessary for clouds formation and precipitation)
		Acceleration and increase of dunes formation

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