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Determination of Soil Characteristics and Degradation Using Geospatial Technologies in the Al Ahsa Oasis

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Abstract

Soil degradation associated with wind and water erosion and physical and chemical deterioration is increasing at an alarming rate worldwide. This research identified soil characteristics and spatial distribution of soil degradation risks in the Al Ahsa Oasis. Several quantitative analytical approaches used geospatial techniques, namely, ArcGIS, Erdas Imagine10, and ENVI 5.3. Six selected remote sensing indices were used, i.e. the salinity index (SI), normalised difference salinity index (NDSI), brightness index (BI), normalised differential vegetation index (NDVI), vegetation soil salinity index (VSSI), and soil adjusted vegetation index (SAVI) software. Field verification monitored the degradation of different types of soil. Samples were collected in May 2019 and processed using satellite images and mechanical and chemical laboratory analysis for 36 samples. The Universal Soil Loss Equation and climatic data were used to measure the annual soil loss rate in the Al Ahsa Oasis. Integration of these datasets resulted in a map of soil degradation values. The results show that the sampled oasis soils have degraded physically, chemically, and biologically. The average physical degradation was 9.93 g/cm^3/year, the average biological degradation was 2.93%/year, and the average chemical degradation was 36.36 mmhos/cm.

KEYWORDS

Biological degradation; chemical degradation; sand dunes; physical degradation; urban sprawl; soil drift

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1. Introduction

Soil degradation is one of the serious environmental challenges affecting agricultural production. Overpopulation, poverty, overgrazing, poor agricultural practices, and lack of appropriate are considered some elements that lead to land degradation (Drechsel *et al.*, 2001; Duraiappah, 1998), but little is known about the interactions between these drivers and the biophysical environment, including biophysical stability domains (Gunderson, 2003).

Integrating a geographic information system (GIS) and remote sensing applications has helped employ a comprehensive methodology of calculating several variables included in statistical equations (Mohamed *et al.*, 2014). The equations and models used for assessing soil erosion and soil degradation and the possibility of estimating losses through the Global Rate of Loss of Soil (RUSL) model are examples.

Remote sensing is a tool recommended for detecting, mapping, and monitoring the problems of different degradation types (Sujatha *et al.*, 2000; Zizala *et al.*, 2018). These problems include the degree of spread and range effects over time (Abdelrahman, 2008).

A GIS is a flexible and powerful tool that can store large volumes of data sets and manipulate and combine different data sets into other sets. These sets can be presented in thematic maps (Al-Mashreki *et al.*, 2010). A GIS can help in measuring soil degradation. A GIS and GPS are combined to provide a good platform for storing a database and presenting the results and development of a user interface.

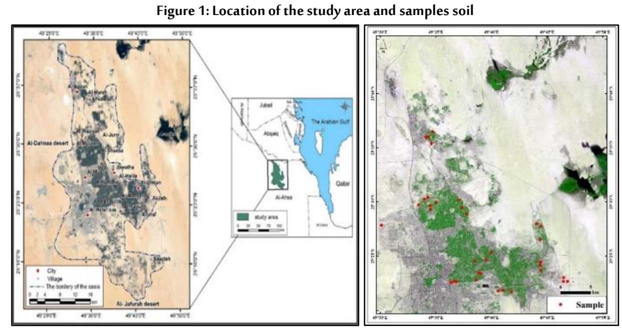
These techniques were used to process the information that characterises and quantifies spatial variation of rational interpolation. Additionally, they were applied to estimate the variance of interpolated values (Stenger *et al.*, 2002).

2. Materials and Methods

2.1. Study Area:

Al Ahsa Oasis is one of the important agricultural areas in Saudi Arabia, covering an area of about 225,000 km^2. The cultivated land is approximately 75,970 km^2. The oasis is located within the tropical desert between Latitudes 25° 10' and 25° 45' N and Longitudes 49° 30' and 49° 50' E (Fig. 1-A). The oasis is bordered by the Al- Dahnaa desert to the west, the marsh of Umm Al-Hamam to the north, the Al-Jafurah desert and the marsh of Al-Tarfa to the south, and the Al-Asfar sabkha and Gulf shore to the east (Al-Barrak, 1993).

Figure 1: Location of the study area and samples soil



A. Location of the study area | B. Locations of samples soil

2.2. Methodology:

Different analyses, including remote sensing, GIS-assisted spatial modelling, and method validating, were used to determine the feasibility of using remote sensing and a geographical information system to map soil salinity and soil degradation directly from the soil, indirectly from vegetation, and with a questionnaire from farmers**.**

2.2.1. Sampling and soil analysis

A survey was conducted in addition to several field visits. Thirty-six samples of disturbed soil (0–30 cm) were collected from 12 sites (Fig.

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1-B). Three samples were taken from each site and put in plastic bags using hand tools.

The samples were taken to the Faculty of Agriculture Laboratory at King Faisal University to determine the type of degradation. Many environmental variables, including Landsat image analysis, elevation, and slope, were considered. This method uses input variables to split sample points into N intervals of equal probability. All samples were air-dried then sieved using a 2 mm sieve. The soil texture, percentage of soft silt, coarse silt, clay, pH, organic material ratio, calcium carbonate, electrical conductivity (EC), and total solids were measured in the saturated paste extracts. EC in the soil was measured to know whether soluble salts exist. In this study, 250 g of air-dried soil was weighed, and deionized water was then added to saturate the soil sample.

2.2.2. Satellite image and software

A Sentinel-2B and Landsat 8 OLI satellite image Level 1T product radiometrically corrected and co-registered to a cartographic projection and terrain corrections was acquired on 22 March 2021, with a resolution of 30 m. The radiometric calibration tool and FLAASH atmospheric correction model of the ENVI 5.3 were applied to the radiometric calibration and atmospheric correction of the satellite images. The geological variation in the area under study is very low. All satellite images were processed by ENVI 5.3. The image was analysed using ArcGIS 10.5, ERDAS Imagine 10, ENVI 5.3, and SPSS statistical software Version 10.

2.2.3. Modelling vegetation and degradation indices

Stressed vegetation can be an indirect sign of degradation in the soil. Six selected remote sensing indices, such as the salinity index (SI), normalised difference salinity index (NDSI), brightness index (BI), normalised differential vegetation index (NDVI), vegetation soil salinity index (VSSI), and soil adjusted vegetation index (SAVI), were used to discriminate and map degradation soils.

2.2.4. Questionnaire from farmers

Fifty questionnaire forms were distributed to farmers to identify the types of chemical fertilizers and pesticides used to control crop insects and to know the sources and types of irrigation used in agricultural land in the Al Ahsa Oasis.

3. Results (Patterns of Agricultural Soil Degradation in the Al Ahsa Oasis)

Patterns of indicators of soil degradation in the Al Ahsa Oasis are variable when considered as an environmental problem. Among those patterns are the high level of groundwater, the high salinity and alkalinity of the soil, and soil exposure resulting from the degradation of the vegetation cover. When wind erosion is activated, the wind erodes the disjointed upper layer of soil, which removes the fine layer of granules containing organic matter, leaving behind the coarse constituents (Al-Bana, 2000). Because of the importance of this topic, FAO has developed a method for directly assessing land degradation by monitoring changes in certain soil specifications (Zucca *et al.*, 2009).

By studying the agricultural soils of the study area, it has been possible to monitor their degradation and verify them in the laboratory by investigating a series of chemical, physical, and biological properties that reflect the regression in the optimal properties of non-degraded soils. The patterns of land degradation can be illustrated as follows.

3.1. Physical Degradation:

Physical degradation is high apparent density g/cm^3/year or low permeability cm/hour/year. Waterlogging and irrigation affect the physical degradation of soil along with crop failure of the whole land surface, heavy machinery use, wasteful irrigation, and rice cultivation. A guide can be used to quantify the physical state of the soil (Balbaa and Naseem, 1994):

$$\frac{ZF + ZC}{C} \tag{1}$$

ZF = Percentage of soft silt (2–20 microns)
ZC = Percentage of coarse silt (20–50 microns)
C = Percentage of clay

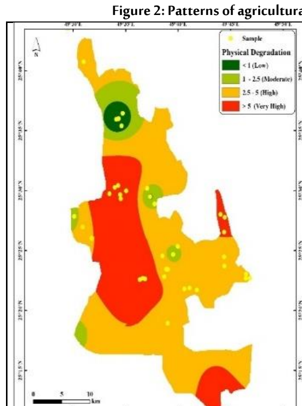
There is a quantitative indication of the physical state of the soil, which is less than 1.5 g/cm^3/year for soils with an on-surface crust and greater than 2.5 g/cm^3/year for soils of large capacity to form a surface crust. Applying Balbaa and Naseem's 1994 equation and based on the results of laboratory analysis (Table 1), the obtained result ranges from 0.87 to 64.29 g/cm^3/year (Table 2), suggesting that the soil of the study area suffers from physical degradation and is susceptible to the formation of a solid shell that is largely impermeable on the surface.

This degradation leads to a decline in soil productivity due to the degradation of its physical characteristics. In fact, this degradation is caused by soil shedding, construction disorder, pore blockage, and the formation of a dried crust. There are many forms of physical degradation, namely, surface crust formation, pore clogging, sand accumulation, and sand dune movement with the poor cover of natural plants. These degradation types include areas exposed to sand creep and deposition and have resulted in the migration of people from these areas due to their desertification. This includes the villages of Al-Omran, Al-Muqam, Jawatha, Al-Kalabiyya, Al-Kawkeeb, Wasit, and Abu Al-Hassa in the northern and northeastern regions of the oasis, with an area of 193.08 km^2 (Fig. 2-A) using the vegetation soil salinity index (VSSI) and the normalised differential vegetation index (NDVI).

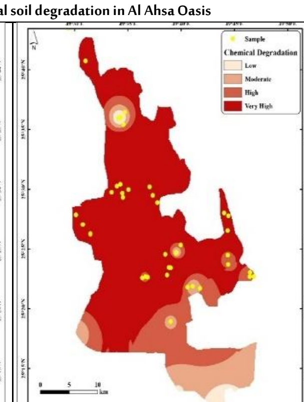
Table 1: Mechanical and chemical analysis of samples from the soil of Al Ahsa Oasis

Sample Source	Silt %	Clay %	Sand %	(1:1) PH	EC mmhos/cm	Organic Material Ratio%	Calcium Carbonate%
Al-Jafer	38	12.56	49.44	8.54	3.75	8.04	20.21
Al-Omran	31	4.28	64.72	8.60	53.6	4.67	21.56
Al-Mansura	58	4.56	37.44	8.80	12.9	5.70	24.28
Al-Battalia	26	8.56	65.44	8.89	13.0	6.56	15.62
Al-Mubriz	30	16.56	53.44	9.14	1.7	5.51	14.94
Al-Shaeba	18	20.56	61.44	8.74	43.3	6.05	15.96
Al-Halila	50	16.56	33.44	9.03	6.4	4.47	16.34
Al-Jurn	62	4.56	33.44	8.51	129.6	4.37	52.98
Al-Waziyah	42	8.56	49.44	9.38	94.4	5.21	14.77
Al-Ayoun	22	12.56	65.44	9.15	1.28	4.46	11.88
Al-Fudhul	56	20.38	23.62	8.62	75.2	5.78	15.11
Al-Marah	36	0.56	63.44	9.62	1.15	6.05	11.37
Average	39.08	10.85	50.39	8.91	36.36	5.57	19.58

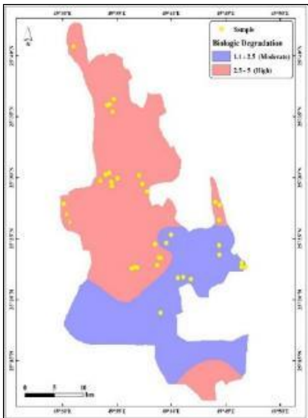
Figure 2: Patterns of agricultural soil degradation in Al Ahsa Oasis



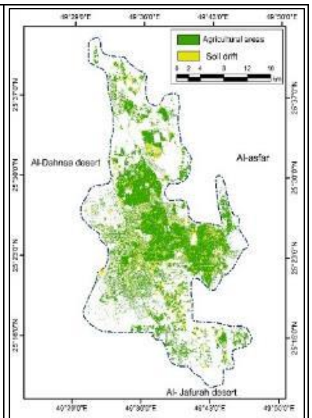
A. Degrees of physical soil degradation



B. Degrees of chemical soil degradation



C. Degrees of biological soil degradation



D. Soil degradation by wind erosion

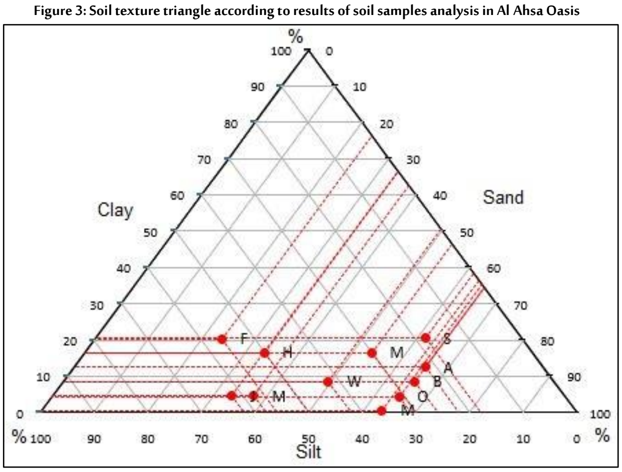
Table 2: Degrees of physical degradation in the soil of Al Ahsa Oasis

Sample Source	Soft Silt %	Coarse Silt %	Clay %	Result	Physical State of Soil*	Degrees of Physical Degradation*
Al-Shaeba	7	11	20.56	0.87	>1.5	Low
Al-Mubriz	18	12	16.56	1.81	1.6–2.5	High
Al-Ayoun	5	19	12.56	1.91		
Al-Omran	15	16	4.28	7.24	<2.5 g/cm^3/year	Very High
Al-Jafer	18	20	12.56	3.02		
Al-Mansura	26	32	4.56	12.72		
Al-Battalia	13	13	8.56	3.04		
Al-Halila	23	27	16.56	3.02		
Al-Jurn	31	31	4.56	13.59		
Al-Waziyah	21	21	8.56	4.91		
Al-Fudhul	28	28	20.28	2.76		
Al-Marah	10	26	0.56	64.29		
Average	17.92	21.33	10.85	9.93		

***Balbaa and Naseem, 1994**

Based on the laboratory analysis results (Table 1 and Fig. 3), it was found that the predominant texture is loam, sandy loam, and silt loam. The clay average was 10.85%, and the sand average was 50.39% of the analysed samples, which indicates that soil in the study area is in the middle category in terms of degradation and erosion processes.

Figure 3: Soil texture triangle according to results of soil samples analysis in Al Ahsa Oasis



3.2. Chemical Degradation:

The manifestations of the chemical degradation of soil characteristics are salinisation, acidosis, alkalinity, and possibly the hardening of the soil surface crust (Balbaa and Naseem, 1994). Saline soils contain relatively large amounts of highly dissolved chloride, calcium sulphate, sodium, and magnesium salts, with electrical conductivity higher than 4 mmhos/cm, a pH of less than 8.5, and osmotic pressure impeding plant growth (Biswas and Mukhejree, 1994).

The laboratory analysis results of soils from the study area are shown in Table 1. The soil texture has the same texture as the sandy loam and silt loam according to the ratios of the three main constituents: silt, clay, and sand. Due to the interference of the three elements, varying degrees of soil overlap are observed in the oasis. The loamy structure texture that is more recognised is considered a good soil in terms of fertility. The soil of the oasis does not have an acidity problem, as the pH value has not fallen below 8.5 in any of the samples (Table 1).

The level of soil degradation can be chemically measured by comparing the levels of salt accumulation, as illustrated in the case of the Al Ahsa Oasis soil (Table 3).

Table 3: Degrees of chemical degradation in the soil of Al Ahsa Oasis

Sample Source	EC mmhos/cm	Electrical Conductivity*	Degrees of Chemical Degradation *
Al-Mubriz	1.7	>2 mmhos/cm	Low
Al-Ayoun	1.28		
Al-Marah	1.15		
Al-Jafer	3.75	3–5 mmhos/cm	High
Al-Omran	53.6	5 mmhos/cm	Very High
Al-Mansura	12.9		
Al-Battalia	13.0		
Al-Shaeba	43.3		
Al-Halila	6.4		
Al-Jurn	129.6		
Al-Waziyah	94.4		
Al-Fudhul	75.2		
Average	36.36		

***Source: Morgan, 1995**

The electrical conductivity values in the soil of the studied area range from 1.15 to 129.6 mmhos/cm, indicating a high level of salt accumulation. The highest value of 129.6 mmhos/cm was reported in the sample collected from the village of Al-Jurn. The lowest value of 1.15 mmhos/cm was represented by the sample from the village of Al-Marah (Fig. 2-B), using the normalised difference salinity index (NDSI), brightness index (BI), and vegetation soil salinity index (VSSI).

The study concluded that the soil of the study area has saline characteristics as a manifestation and evidence of the chemical degradation of the soil, along with the hardening of the surface crust of the soil in most of the Al Ahsa Oasis. These areas include the villages of Al-Waziyah, Al-Halila, Al-Fudhul, and Al-Mansura (Fig. 4) and the cities of Al-Ayoun and Al-Omran. These soils suffer from a moderate degree of salinity extending from the city of Al-Ayoun to the villages of Al-Mutairfi, Al-Jalijla, and Al-Tarf, east of Al-Mubarraz and south of Al-Hofuf, with a total area of 20.53 km^2.

Figure 4: Salinisation and soil drift by the wind in Al Ahsa Oasis

A. Salinisation is a manifestation of chemical degradation in Al-Fudhul village

B. Soil drift by the wind in the city of Al-Omran

The salted soil is also highly prevalent in the villages of Beni Ma'an, Al-Batalia, Al-Mansoura, Al-Qur'in, Al-Jiljila, Al-Shaqiq, Al-Jafer, and Al-Tweithir and the city of Al-Ayoun, with an area of 61.65 km^2. In addition, the soil suffers from very high salinisation to the east of Jebel Al-Garah and the surrounding area of Al-Tahimiya village as well as the area around Al-Jisha village and the area north of the villages of Al-Jayjal and Al-Qurn up to the northern covering borders of the oasis, an area of 79.85 km^2.

3.3. Biological Degradation:

The direct result of biological deterioration is the lack of organic matter in the soil, causing physical degradation, nutrient deficiency, and drift. This is caused by any non-drifted dissolution of organic material. The rate of loss of organic matter resulting from the impact of terrestrial calcium carbonate is estimated in accordance with the Reny and Marin equation (Balbaa and Naseem, 1994).

$$K_2 = \frac{1200}{(A+200)(C+200)} x100$$

K_2 = Annual rate of loss of organic matter
A = Percentage of clay
C = Percentage of calcium carbonate

Application of this equation to the soil samples of the study area (Table 4) indicated that the soil suffers from a high degree of biological degradation according to Balbaa and Naseem's 1994 estimates, with an annual loss rate of organic material ranging between 0.8–5.1%, with the city of Al-Jafer being low, Al-Mubarraz and Al-Batalia medium, and Al-Omran and Al-Ayoun the highest along with the villages of Al-Mansura, Al-Shaeba, Al-Halila, Al-Waziyah, Al-Fudhul, and Al-Marah. The highest rate was found in Al-Jurn (Fig. 2-C).

Table 4: Degrees of biological degradation in the soil of Al Ahsa Oasis

Sample Source	Clay %	Carbonate %	Annual Rate of the Loss of the Organic Material %	Loss of the Organic Material*	Degrees of Biological Degradation *
Al-Jafer	12.56	20.21	0.8	>1%/year	Low
Al-Battalia	8.56	15.62	2.4	1–2.5%/year	Medium
Al-Mubriz	16.56	14.94	2.2		
Al-Omran	4.28	21.56	2.6	2.5–5%/year	High
Al-Mansura	4.56	24.28	2.7		
Al-Shaeba	20.56	15.96	3.2		
Al-Halila	16.56	16.34	3.1		
Al-Waziyah	8.56	14.77	4.2		
Al-Ayoun	12.56	11.88	2.9		
Al-Fudhul	20.28	15.11	3.3		
Al-Marah	0.56	11.37	2.6		
Al-Jurn	4.56	52.98	5.1	<5%/year	Very High
Average			2.93		

***Source: Balbaa and Naseem, 1994**

3.4. Soil Drift by Wind:

This type of degradation is the most important and widespread degradation process in the study area, resulting in sand creep at a rate of 5–9 metres, with an annual average of 6.8 metres (Abdelhamid, 2007). The north, northeast, northwest, and south wind gusts cause the loss of fertile topsoil that spreads in Al-Omran (Fig. 4), Al-Muqaddam, Jawath, Al-Kalabiya, Al-Koekb, Wasit, and Abu al-Hass (Abu al-Khair, 1984). It spreads in the flat layer or riparian plains and sandy soil. The soil drift occurs when strong winds blow into unprotected soil, intensifying dry and disjointed soil. Figure 2-D displays the distribution of lands affected by soil drift, constituting a total area of 66.99 km^2.

4. Discussion

4.1. Causes of Soil Degradation in the Al Ahsa Oasis:

Many physical and human factors have contributed to the soil degradation in the Al Ahsa Oasis; they are presented as follows.

4.1.1. Soil characteristics

The soil of the Al Ahsa Oasis is a sedimentary formation from the quaternary that consists of sandstone, limestone, clay, and loam (Al-Taher, 1999). Based on the laboratory analysis of soil samples, it was found that the dominant texture is loam, sandy loam, and silt loam, which is in the middle group based on classification (Husenbiuiler, 1985). This means that the value of the soil's drift varies from 105–195 ton/ha/year.

The drifting potential of soils can also be determined according to the prevailing texture through indicators suggested by FAO. Based on the laboratory analysis results (Table 5), it was found that the average clay ratio was about 10.85%. In comparison, the average sand ratio reached 50.39% of the components of the samples analysed, indicating that soils of the study area are in the middle category in terms of probability of degradation and drift. The study concluded that some factors lead to the rapid degradation and erosion of the soil; these factors depend on the structural and textual characteristics of the soil.

Table 5: Percentage of clay and sand in samples from the soil of Al Ahsa Oasis

Sample Source	Clay %	Sand %	Sample Source	Clay %	Sand %
Al-Jafer	12.56	49.44	Al-Halila	16.56	35.44
Al-Omran	4.28	64.72	Al-Jurn	4.56	33.44
Al-Mansura	4.56	37.44	Al-Waziyah	8.56	49.44
Al-Battalia	8.56	65.44	Al-Ayoun	12.56	67.44
Al-Mubriz	16.56	53.44	Al-Fudhul	20.28	23.62
Al-Shaeba	20.56	61.44	Al-Marah	00.56	63.44

4.1.2. Climatic factors

Climatic factors contribute to increasing the effectiveness of soil degradation. The data of the Al Ahsa meteorological station, located at Latitude 25 17 53 N and Longitude 49 29 11 E and at the height of 178.17 metres, where an influence extends 50 km, shows the following results (Table 6):

- The minimum temperature values are 8.5°C and decrease during the winter months to an average of -0.5°C, while the maximum temperatures are 45.7°C and rise during the summer months. The significant difference between the minimum and maximum values in the summer and winter average temperatures and the large quarterly temperature range of about 37.2°C has a considerable effect on salinisation processes and, therefore, the chemical degradation of the soil in the oasis.
- The average annual rainfall is 6.9 mm, while the annual evaporation rate is 12.8 mm. The environment is arid, with high evaporation rates not allowing for any runoff level, thus leading to soil degradation.
- The maximum daily amount of rain is about 56.2 mm, the annual wind speed rate is 7 knots, and the maximum wind speed is 80 knots; this causes the soil surface layer to drift.

Table 6: Monthly averages of some climatic elements of Al Ahsa station

Month	Temperature (°C)		Vapor	Surface Wind (Knots)		Rainfall (mm)	
	MX	MN	M	M	Max Speed	M	24-Hour Total (Ext.)
01	21.2	8.5	9.2	7	36	15.0	50.6
02	24.2	10.6	9.5	8	40	11.6	28.9
03	28.9	14.3	10.5	8	60	16.2	56.2
04	35.1	19.6	12.7	7	80	10.7	21.1
05	41.5	24.9	13.1	7	45	2.1	15.3
06	44.4	27.6	12.6	8	40	0.0	.3
07	45.7	29.4	14.2	8	42	0.0	1.1
08	45.4	28.9	17.7	7	39	0.9	19.4
09	42.3	25.3	16.0	6	38	0.0	.0
10	37.6	21.1	14.7	5	40	0.6	6.7
11	29.9	15.6	12.4	6	41	5.1	27.9
12	23.4	10.5	10.5	7	39	21.1	51.9
Maximum	45.7				80		56.2
Mean			12.8	7		6.9	

Source: General Authority for Meteorology and Environmental Protection, 1985–2018

4.1.3. Terrain factors

The Al Ahsa Oasis is surrounded by the rocky edge of the Ghawar Desert in the west and sand dunes covering the adjacent plain in the east. Most parts of the oasis lie between 100–250 m above the mean sea level. This plain slopes towards the east with a slight gradient of about 1 km (Al-Sayaria and Zotl, 1978). The surface of the Al Ahsa Oasis is even with a gradual decline to the east and northeast from 250 metres above sea level at the Othmaniyah mountain and Shadqam to the west of the Al Ahsa Oasis. The Al Ahsa Oasis also declines from 150 metres at the western boundary of the oasis to 125 metres at the eastern boundary down to 25 metres at the Al-Uqair near the western coast of the Arabian Gulf (Al-Taher, 1999).

Consequently, the morphological features of the oasis allowed natural drainage by moving the irrigation water excess in the oasis in the general slope direction. This has led to the groundwater level being elevated in the oasis's agricultural fields, sabkha and swamps forming within and around the agricultural land from the east, north, and south, soil salinity increasing, and waterlogging, resulting in the deterioration of soil properties.

4.1.4. Irrigation water

The Al Ahsa Oasis is characterised by an excess of groundwater, with hydrological estimates indicating a contribution of 141.9 million m^3/year, with 887 wells and 102 springs (Irrigation and Drainage Authority, 2019). Groundwater salinity values in the oasis vary from one aquifer to another. In general, salt concentrations in groundwater formations of the oasis increase from west to east in the direction of the groundwater flow due to long-term interaction between water and rock formations in high temperatures and a low recharge and high pumping rate (Al-Khatib, 1980). The salinity values of the groundwater range from 1,036 to 7,601 ppm with the Neogene, Umm Al-Radhma, and Al-Wasie formations in the Al Ahsa Oasis (Irrigation and Drainage Authority, 2019).

In general, when method salts accumulate in the soil after the water evaporates, the groundwater can cause land degradation and desertification due to using groundwater for irrigation by inundation. The excessive use of irrigation water by farmers also causes groundwater levels to rise to the level of the capillary property so that water containing salts moves to the surface. Under high evaporation conditions, salts are deposited in the pores of the soil and on the surface (Al-Zubeidi, 1994). When formed, the salt crust is weathered by the wind, then gravity causes it to fall downward, affecting the soil formation in the vicinity (Briggs *et al.*, 1997).

The water system in the Al Ahsa Oasis was naturally balanced, but in the early 1960s, with the discovery of oil, the oasis experienced excessive well drilling, causing some springs to dry up, and water balance in the area began to deteriorate (Al-Gabr, 2002).

It should be noted that domestic, industrial, and agricultural demands for water in the Al Ahsa region doubled from 10.125 m^3/sec to 20.689 m^3/sec during the period from 1977 to 2010 (Irrigation and Drainage Authority, 2019). The annual flow rates of the main springs also varied from 229.016 million cubic metres to 213.541 million cubic metres during the period from 1974 to 1983 (Al-Gabr, 2002). The adverse effects also began with the depletion of natural springs followed by a large number of the wells during the period from 1990 to 2002, with lower and deeper nutritional gaps. This has resulted in significantly reducing the contribution of the irrigation and drainage project from 7.1 m^3/sec to 2.4 m^3/sec (Kuwaity and Ahmed, 2003).

Consequently, because of increased water consumption in the study area in addition to climatic conditions (in terms of temperature rise and an increase in evaporation capacity), low flow rates, and the depletion of several springs and wells, the soil condition has been affected and salinisation has increased, especially in the total root area of plants during droughts between irrigation. This ultimately led to the degradation of soil characteristics.

4.1.5. Sand dune creep

Sand and sand dune creep play an important role in increasing soil degradation, as the biological capacity of agricultural soil decreases or disappears once and for all (Ghanimi, 1997). The sand dunes cover large areas in the study area, namely, the Jafurah Desert, which is on the northern, eastern, and southern boundaries of the Al Ahsa Oasis. Sand dunes in the study area move at a rate of 5–9 m/year, with an annual average of 6.8 metres, where the eastern and central regions are the most mobile and active (Abdul Hamid, 2007). The yearly average amount of sand drift is 12.7 m^3/m (Al-Taher, 1996).

Sands around the oasis have become vulnerable to creep as a result of northern, northeastern, northwestern, and southern winds affecting the oasis because of its geographic location in the middle of the desert, thus invading cultivated areas in the northern and northeastern sides, such as Al-Omran, Jawatha, and Al-Kalabiyya. The Wakutty survey in 1963 shows that the total cultivated area in the oasis was 80.94 km^2, which decreased to 40.45 km^2 in 1965. This situation is apparently a result of sand dune creep and the deteriorating condition of the soil (Al-Gabr, 2002). Generally, sand creep devours about 0.23 km^2 of farmland annually (Irrigation and Drainage Authority, 2019).

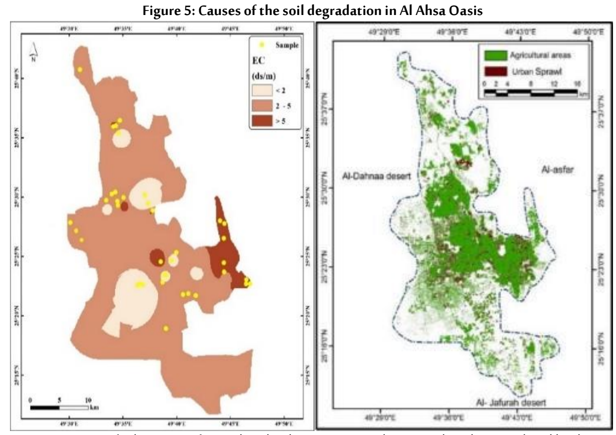
4.1.6. Soil salinisation

As a result of the worldwide expansion of dryland farming, salinisation and waterlogging are recognised as signs of land degradation. Salinisation problems are associated with poor drainage and soil erosion (Williams and Balling, 1996). A study by Al-Dakheel (2011) indicates that the salinity-affected land area of the Al Ahsa Oasis is constantly increasing over time due to the excess of the salinity of irrigation water. The shortage of water required for irrigating the cultivated lands, resulting in the reuse of agricultural wastewater in many areas of the oasis at varying mixing rates and sometimes with no mixing, leads to wastewater irrigation.

This is in addition to the high salinity of groundwater in the Al Ahsa Oasis due to excessive and uncentred pumping from water-bearing layers, increasing the salinity of wells and salt accumulation in agricultural soil.

Based on the use of the salinity index (SI), normalised difference salinity index (NDSI), and the vegetation soil salinity index (VSSI), figure 5-A shows that the sandy soil structure of the studied area has a very high salinity (more than 5 mmhos/cm) concentrated in the areas east of Mount Al-Qarah and the surrounding area, around the village of Al-Omran, and the area north of the villages of Al-Jilijla and Al-Qurn up to the Al-Ayoun city boundaries. The areas of high salinity (2–5 mmhos/cm) are in Al-Jefer, Al-Asfar, and some areas around the villages of Al-Shuqaiq and Al-Jalilah. The other three categories are limited, where the least affected zones are around the Umm Khodod and Ain Umm Sabaa. This indicates the severe degradation of the soil condition in the Al Ahsa Oasis and its subsequent exposure to desertification (Al-Dakheel, 2011).

Figure 5: Causes of the soil degradation in Al Ahsa Oasis



A. Degrees of salinisation of agricultural soil   B. Urban sprawl on the agricultural land

4.1.7. Population growth

According to the most recent census (2019), the oasis has more than 1.51 million inhabitants, while in 1986, the total population was only 237,721 (Al Ahsa Municipality, 2020). This rapid population growth (0.61%) will undoubtedly result in population pressure on water resources and attempts to intensify usage of agricultural soil, leading to the degradation of soil characteristics.

4.1.8. Urban sprawl

The extension of urban blocks at the expense of agricultural land is a pause and reduction in the biological productivity of agricultural soil, making it one of the most important causes of agricultural soil degradation and desertification (Thomas and Middleton, 1994).

The Governorate of Al Ahsa's 1435 census indicated that 598 new families had been added since the 1905 census. Thus, free-load lots are needed to set housing facilities for accommodation. Agricultural lands in the outskirts of cities have been a targeted area for providing more housing units. While the number of households increased by 37.9% between 1905 and 2019, the amount of farmland decreased from 113.31 km^2 to 68.70 km^2 during the same period (General Authority for Statistics, 2020). While not all the agricultural land of 17.20 km^2 has been reserved for residential purposes, there are other agricultural land uses. Yet urban sprawl has shaped most of the agricultural land.

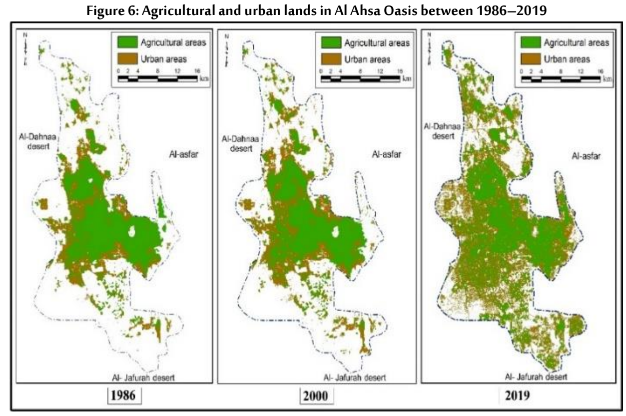
It should be noted that urban sprawl on agricultural land is carried out by the government, which can be regarded as an official urban encroachment of the government and local administration. This alone cut out some 43.75 km^2 of agricultural land for urban uses between 2000 and 2019 (Fig. 5-B). Examples of urban growth at the expense of agricultural land include the plantation scheme in the southeast of the Al Ahsa Oasis and the Munifa residential scheme in the city of Al-Hofuf.

According to the Survey and Planning Authority (2019) data, 1974 witnessed a reduction in the cultivated area, from 71.43 km^2 in 1969 to 59.76 km^2 in 1974. Even though it increased to 71.79 km^2 in 1980, it declined to 71.32 km^2 in 2019. This fluctuation is because there are areas in the oasis where agricultural lands have shrunk, namely, the areas between the cities of Al-Hofuf and Al-Mubarraz, represented by Al-Seifah, Umm Khrisan, Ain Al-Zawawi, Ain Al-Morjane, and Al-Qilaybat. The cultivated area was 3.04 km^2, which has been reduced by half due to urban expansion at the expense of agricultural land.

From the field survey and interviews with farmers in the study area, it has been found that agricultural areas located south of Al-Hofuf city that existed in 1971 have completely disappeared, including Ain Umm Al-Hamir, Asilah, Tawilibiyah, and Sarafiyah. The area, which is about 0.04 km^2, was turned into residential areas carrying the same names and is now located in the centre of the city of Al-Hofuf, including Al-Thalithiya, Al-Mazruia, Al-Sindiya, Al-Murabdiyah, and Al-Wasitah. As for Al-Raqqa, the area had more than 40 hand-dug wells, and about 2.53 km^2 grain-cultivated land had been converted into residential houses and blocks of the same name; Al-Sharafiyah area and southwest of Ain Al-Haara east of Al-Mubarraz. Urbanism above the ground became the dominant manifestation after the disappearance of agricultural land.

These results were confirmed by the study and analysis of satellite scenes in 1986, 2000, and 2019. The decline in cultivated areas was observed in contrast to the increase in urban areas (Fig. 6). The area under cultivation was 145.47 km^2 in 1986, while it became 114.43 km^2 in 2000 and decreased to 82.92 km^2 in 2019. The area is growing steadily in terms of urban areas, from 157.6 km^2 to 167.85 km^2 to 231.77 km^2 in 1986, 2000, and 2019, respectively.

Figure 6: Agricultural and urban lands in Al Ahsa Oasis between 1986–2019



4.1.9. Agricultural practices

Farmers in the study area rely on some agricultural practices that increase rates of qualitative soil degradation. The most important one is submerged irrigation resulting in increased soil salinity (Al-Zubeidi, 1994), characteristic of most dry and semi-dry areas. This happens because of increased evaporation/evapotranspiration and less precipitation. Salts then accumulate because there is insufficient rain to wash the soil. Inundation leads to high groundwater levels approaching the earth's surface, which means that the plant's root area is saturated with water and cannot get sufficient air for respiration. These elements lead to a deterioration in agricultural soil characteristics, gradually reducing its productivity.

The increased irrigation by farmers has also resulted in increased water and soil salinity due to doubling irrigation to twice a week in winter and from three to four times in summer (Al-Zubeidi, 1994). This irrigation system has prevailed because of the water requirements of the main crops of palms and rice. The poor water retention of sandy soil and high evapotranspiration also lead to the same result. These environmental risks of irrigation increase if irrigation water quality decreases, such as the high salt concentration (1,430 to 6,440 ppm) of groundwater used for irrigation (Ministry of Environment, Water, and Agriculture, 2019).

The study area suffers from groundwater pollution (Irrigation and Drainage Authority, 2019). Since wells are the only water source, continuous pumping from groundwater aquifers has led to low groundwater levels and high concentrations of dissolved salts and iron and manganese salts. The first leads to salinisation and desertification of soil. Iron salts in the water of the wells reached more than 7,601 ppm, causing a serious problem when modern irrigation systems are applied. This is because of blocking sludge due to the deposition of iron salts. Soluble salts in water also erode pipes used for spray irrigation, thus deteriorating agricultural soil, ultimately leading to unsuccessful agriculture.

Digging irrigation canals at higher levels than the agricultural soil is an improper irrigation method, increasing the degradation process, especially in permeable soils. It salinises the soil, causing poor biological capacity that may reach full infertility, becoming a biologically dead soil, a very severe state of desertification. This has occurred in the villages of Al-Weziyah, Al-Mutarifi, Al-Halila, and Al-Ayoun, where the water level is insufficient for irrigation water supply and transport by gravity. It is, therefore, necessary to transport irrigation water manually, exposing the soil to saline infiltration, degradation of its properties, and subsequent desertification.

In addition, farmers in the oasis grow several crops, the most important of which are rice, vegetables, and fruits, cultivated simultaneously with palms. Thus, soil saturation is increased, especially in the case of the near-surface caterpillar layer, leading to waterlogging, salinisation, and degradation.

4.1.10. Soil pollution

The study area suffers from soil contamination resulting from chemical fertilizers and pesticides where farmers use nitrogen and phosphate fertilizers. Nitrogen is considered the main chemical ingredient that needs to be added to the soil. The oasis consumes about 3,129.6 tons/year of azotic fertilizer and about 506 tons of phosphate fertilizer, where phosphate is used during the land preparation stage (Directorate of Agriculture, 2019). The excessive fertilizer amount not used by plant roots is estimated as 25% (El-Amrawi, 1997). In other words, the loss of nitrogen fertilizers is about 782.4 tons, and that of phosphate fertilizers is about 126.5 tons during a single agricultural season. Farmers also use animal waste as an organic fertilizer, estimated at 89.15 tons, which varies from one farmer to another (Directorate of Agriculture, 2019).

Although adding organic fertilizers can increase production, improve the soil's physical quality, and provide important nutrients such as nitrogen, phosphate, and potassium, it causes contamination of heavy metals and salts. Additionally, the soil and crops will be subject to bacteria and pathogenic microbes infection.

Pesticides pollute the soil because of the excessive unregulated use by farmers during pest resistance. In the study area, it was concluded that the surveyed sample of farmers used six types of pesticides: organic phosphorus, manufactured pyrethroids, carbamates, growth organisation pesticides, manufactured nicotine, and acaricides to control crop-harmful insects (Tayseer and Al-Saikhan, 2011). Thus, the irrational use of chemical fertilizers, pesticides, and agricultural sewage water can be regarded as land degradation problems in the study area.

4.2. Proposals to Protect Soil from Degradation:

Based on the field survey, several attempts have been made by oasis farmers and governmental agencies to resist land degradation. These methods are illustrated below.

The wind is one of the main factors that causes soil drift and sand creep in the Al Ahsa Oasis, in addition to a lack of vegetation cover. Therefore, governmental agencies sought to resist soil degradation in the study area by constructing the sand reservation project northeast of the oasis in 1962, which is 20 km long and 250–750 m wide. This protects the southeastern parts of the oasis.

The various protection methods in the project are mechanical. These include using equipment to transport the sand, digging trenches to break and settle the sand, building dry fences from palm plumage, putting polyethylene, block, or cement walls, and growing green belts using drought-tolerant, saline, and high wind-resistant trees. Eighteen species are grown in the project, the most important of which are Tamarix, Prosopis, Eucalyptus, Casuarina, and Acacia. One chemical method is spraying asphalt, raw oil, or chemicals on sand dunes. It should be noted that these methods are also used throughout the oasis (Al Ahsa National Park Administration, Al Ahsa, 2019).

The soil of the Al Ahsa Oasis is fragile, of low depth, and poor in organic matter; therefore, farmers apply the following methods to preserve soil:

- Establishing a specific programme for drilling and monitoring wells to avoid problems arising from dried wells and reduced water levels
- Rationalising the use of irrigation water by introducing sophisticated and economical irrigation systems such as drip irrigation in some parts of the oasis, including in the city of Al-Omran and the villages of Al-Weziya, Al-Jarn, and Al-Bataliah
- Rehabilitating agricultural soil degraded by salinisation by washing and adding soil conditioners such as gypsum (farms are given four excess irrigations to remove salts from the soil sector), by constructing banks, and by obligating farmers to work out exposed field banks inside their farms to collect salts from wastewater
- Treating the waterlogging of soil resulting from poor drainage in the oasis by draining the wet sabkhas, raising the efficiency of field drains and linking them to the main drains, and cleaning the main drains to prevent the return of water back to the farms, or by adding gypsum to the waterlogged soil before washing, as in the case of the village of Al-Marah

Based on the above, the study recommends several ways to reduce land degradation in the oasis:

- Trend towards land reclamation in the Al Ahsa Oasis, especially in the west, and use a new agricultural cycle to reduce soil degradation
- Use mechanical barriers with biological barriers to combat sand creep and sand dunes in agricultural soil
- Use biological pest resistance and return to organic fertilizers to combat chemical soil pollution and degradation
- Conserve available water resources through the rationalisation of irrigation processes and human uses to reduce the depletion of wells
- Resist soil degradation through soil drift control, sand creep resistance, and regulating of agricultural processes, as seen in the Al Ahsa Oasis

5. Conclusions

Through discussion and analysis based on the use of geospatial techniques and field verification, the following were identified:

- The soil suffers from three types of degradation. The first is physical deterioration. There is evidence of from 0.87 to 64.29 g/cm^3/year in the villages of Al-Shaeba and Al-Marah; therefore, the soil is exposed to the formation of a solid crust that is not implemented on the surface. The second is chemical degradation, evidence of which was the electrical conduction of the soil of the research area ranges from 15 to 129.6 mmhos/cm^1. This indicates a high level of salt accumulation in these areas, especially in the villages of Al-Marah, Al-Waziyah, Al-Mansura, and Al-Fadhul. And the third is the biological degradation of the soil that expresses the loss of and the high suffering from the organic matter in the soil, 0.8–5.1% annually, meaning that it experiences elevated degradation in Al-Omran, Al-Ayoun, and Al-Jurn.
- The highly degraded soil covers an area of about 277 km^2, which accounts for 0.36% of the total cultivated area of the oasis. The average degraded soil area is 149 km^2, accounting for 0.20% of the total area of the oasis. The lower degraded soil area is about 174 km^2, which accounts for 0.23% of the total area of the oasis.
- The factors affecting land degradation were the human factor of population growth at an average rate of 0.61% per year, putting pressure on agricultural resources; poor agricultural practices using submerged irrigation and growing water-intensive crops; the urban sprawl on agricultural land as a result of the 19.6% increase in the number of households during the period from 1986–2019; using nitrogen fertilizers (3,129 tons), phosphates (1,506 tons), and organic fertilizers (89.15 tons) resulting in soil and groundwater pollution; and natural factors, including characteristics of the water and soil, climatic conditions, the drying up of wells, and salts at 7,601 parts per million.

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