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EVALUATION OF SOIL DEGRADATION IN AL-KHARJ CENTRE, SAUDI ARABIA USING REMOTE SENSING

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Abstract

Land degradation is a great threat to the world, not merely as an environmental issue, but also a social and economic problem. Therefore, identification of land degradation is essential to check the problem and implement the remedial measures needed. This study presents the main results of a thorough evaluation of land degradation in Al-Kharj Centre, Saudi Arabia. The study was carried out as part of a project aimed to study features and causes of land degradation in Saudi Arabia. An integrated approach for evaluating soil degradation was adopted in this study, through the combined analysis of satellite imagery and supported by fieldwork and previous work done in the region. The results revealed that the cultivated areas covered an area of about 820 km2 which dropped to 505 km2 in 2001. Remote sensing was used for monitoring changes in the cultivated area and its relationship to land degradation. The decrease in the cultivated area from the year 1993 through 1997 and 2001 was used as an indication of land degradation and linked to normalized difference vegetation index as determined from remote sensing data for the period 1993 through 2001. Principal component and unsupervised classifications were used to identify the ground features which could be related to land degradation. It was concluded that 10 units were more appropriate to show the cultivated area clearly with no overlapping with other units. Verification by field trips (ground truth) indicated that there are three basic units and several sub-units in the area studied. The results indicated that salinization, water quality, sand creep, and wind erosion represent the major types of land degradation in the studied area.

Key words: Soil Degradation, Salinity, Saudi Arabia, Remote Sensing

Introduction

Land degradation is defined as the long-term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover independently. It had been a major global issue during the 20th century and will continue to gain concern in the international agenda in the 21st century. The importance of land degradation among global issues is gaining more attention because of its impact on world food security and quality of the environment [1]. Land degradation is frequently attributed to human causes [2]. Worldwide, it is estimated that nearly two billion hectares of biologically productive land have been rendered unproductive due to irreversible degradation [3]. The rate of land degradation is estimated at 5 to 7 million hectares per year, suggesting that about 0.30% to 0.50% of the world’s arable land is lost annually due to soil degradation [4, 5]. In the context of productivity, land degradation results from a mismatch between land quality and land use [6].

In Saudi Arabia, there are various factors involved in land degradation, including climatic variations and human activities. [7] suggested that Holocene land degradation probably began around 5,500 BP caused by a southward shift of the monsoon winds and their associated precipitation [8]. With less precipitation, particularly in the eastern region, grasslands were probably replaced by open shrub land and dune systems reactivated.

In recent years large areas of desert in Saudi Arabia have been turned into agricultural fields– a major accomplishment in a country that receives an average of about 100 mm/year, one of the lowest rates in the world. Mismanagement regarding land use is aggravated by overexploitation of water and land resources, over cultivation of marginal lands, and the use of inappropriate technologies. [9] investigated the irrigation water used for wheat and alfalfa in the Al-Qassim region of central part of Saudi Arabia. The water had an average salinity of 2,375 ppm but was as high as 8,200 ppm. They calculated that between 16.6 and 83 tons per hectare of salt was deposited in the soil per season. Two degrees of salinity were differentiated using computer aided multispectral data analysis system [10]. Desert soil surface feature, like desert pavements, surface accumulation of salts, $CaCO_3$ and surface exposure of gypsum materials are manifestations of some kind of land deterioration in semi-arid regions. Mapping of spatial distribution and extent of these features would be relevant in different aspects of environmental studies especially in areas vulnerable to land degradation in arid regions. Several researchers have attempted to detect the distribution and severity of soil salinity with either visual or computer remote sensing techniques, or using combination of both methods. [11] presented a study in which Landsat Thematic Mapper (TM) data have been used to identify and map saline areas of Nile delta in Egypt with reasonable accuracy. Using remote sensing for mapping and monitoring salt affected soil has also been studied [12]. Their study concluded that the degree of soil salinity influences the land cover and land-use pattern as a result of which these units exhibit different tone, texture and pattern on the TM image.

In recent decades, there has been a widespread application of remote sensing data to map soil salinity, either directly from bare soil or indirectly from vegetation in a real-time and cost-effective manner at various scales [13]. Remote sensing techniques have been widely applied to identify and characterize degraded land and to monitor the trends of degraded land and desertification. However, due to the lack of perception and information about the environmental state, different physical and social background, no satisfactory evaluation system of degraded land has been adapted to the specific characteristics of each ecosystem. Previous research in the studied areas revealed that soils of the area under investigation were marginally suitable or non-suitable for agriculture. Soil degradation map of Saudi Arabia based on Global Assessment of Soil Degradation (GLASOD) map, [14] showed that the area under study is severely degraded. Nonetheless, in recent years, most of these soils which were classified as unsuitable largely introduced for crop production. Generous subsidies from the government plus the use of modern technology for water drilling and sophisticated irrigation system enabled the farmers to turn these soils to productive soils.

Land degradation in Saudi Arabia is a matter of urgency and must be accorded greater significance on the environmental agenda. A legal framework should be created to protect these environmental assets.This research attempts to provide a synthesis and analysis of the state of land degradation in Al-Kharj, Saudi Arabia. The research also focuses on the limitations and causes of degradation in relation to the existing management practices. The study area falls under Al-Kharj Centre that has an arid climate. This area is considered as one of the most agricultural important areas in the Kingdom of Saudi Arabia that offers valuable ground water potential. Finally the present study aimed to characterize the major land degradation indicators in Al-Kharj Centre and suggest better conservation strategies and management options.

Materials and Methods

Study Area

Al-Kharj governorate (Figure 1) lies southeast of Riyadh, the national capital. It has grown into a flourishing agricultural oasis, producing cereals, dates, vegetables, and fruits. Al-Kharj governorate lies between 24° 8′ 54″ N, 47° 18′ 18″ E covering an area of about 11000 km^2. The study area has an aridic climate, characterized by hot summer and cold winter.

Figure 1. Study Area

Methods

An integrated approach for evaluating soil degradation in Al-Kharj Centre was adopted in this study, through the combined analysis of satellite imagery, supported by field work and previous work in the region. This approach consisted of three steps namely; identification of the changes in the cultivated area by comparing the dates of the successive Landsat images through the analysis of Normalize Density Vegetation Index (NDVI) and vector generation. Second to identify surface features associated with the land degradation (e.g., salinization, erosion, and sand creep). Different techniques for image processing have been applied. These techniques include both Principal Component Analysis (PCA) and unsupervised classification. Images of satellite Landsat-5 for the years between 1993 and 2001 of the study area were used as a basis for the digital processing. Table 1 and 2 show the specifications of satellites used; note that the entire original satellite images with the following specifications:

Orientation: Satellite
Resampling: NN.
Forma: Eosat Fast Format for Landsat-TM or Spim for Spot image.
Product type: Level-2a.
Organization: BSQ for TM, BIL for Spot.

Table 1. Landsat-5 specifications

Satellite	Sensor	Technical specifications
Landsat-5	TM	The coverage frequency: every 16 days. The area coverage was: 185 × 185 km IFOV: 28.5 meters. Radiation accuracy: 8 bit The degree of gray scale: 0-255 The number of TM bands: (7) Bands range is: Range 1 (0.45- 0.52 μm) Blue Range 2 (0.52- 0.60 μm) Green Range 3 (0.63- 0.69 μm) Red Range 4 (0.76- 0.90 μm) Reflective infrared Range 5 (1.55- 1.75 μm) Mid-infrared Range 6 (10.40- 12.5 μm) Thermal-infrared Range 7 (2.08- 2.35 μm) Mid-infrared

Table 2. Spot-4 specifications

Satellite	Sensor	Technical specifications
Spot-4	XS Pan	Coverage frequency: every 26 days. Area of coverage: 60 × 60 km IFOV: XS 28.5 meters. Pan = 10meters Radiation accuracy: 8 bit The degree of gray scale: 0-255 The number of XS bands: seven spectral bands and a range is: Range 1 (0.50- 0.59 μm) Green Range 2 (0.61- 0.68 μm) Red Range 3 (0.79- 0.89 μm) Reflective infrared The number of Pan bands: Range 1 (0.51- 0.73 μm)

Radiometric correction for Landsat images of the selected study area was done using improved dark object subtraction technique. Geometric correction for the Orthro rectification of spot image was generated by using image technique. Digital processing of the images was carried after making primary corrections in accordance with the primary objective of the research. To identify the characteristics of ground features, and how it spread through the analysis of satellite images principal component analysis and unsupervised classification have been made. Several attempts were made for the classification and the latest satellite images used for the study area in a way that helps to identify areas with degraded soils, which can show features of specific type of degradation such as surface salinity. Finally, the ground truth was done through several field trips to the study area which identified a number of sites experienced a decline in productivity.

Analysis of Soil Samples

A representative soil samples collected during fieldwork was air-dried, sieved using 2-mm sieves and used for chemical analysis. The pH and EC values of soil samples were measured using 1:50 ratio of w/v with distilled water by pH-meter and the electrical conductivity meter, respectively.

Results and Discussion

Remote Sensing

Remote sensing was used for monitoring changes in the cultivated area and its relationship to land degradation. Visual interpretation of Landsat-TM imagery data (Band, 1, 2, 3, 4, 7) obtained at fixed dates and different years was adopted in this study. The decrease in the cultivated area from the year 1993 through 1997 and 2001 was used as an indication of land degradation and linked to normalized difference vegetation index (NDVI) as determined from remote sensing data for the period 1993 through 2001. The percentage of green vegetation (both agricultural and natural was determined using the model which relates the vegetative cover to NDVI. The natural vegetation cover constitute only small area in the region hence, it was ignored. Data show that agricultural areas in the region of cultivated area in Al-Kharj Centre was 820 km^2 and declined gradually till 1998, while slight increases was registered in 2001 (Table 3, Figure 2, 3 and 4).

Table 3. Cultivated area based on NDVI analysis

Area	Satellite	Year	Cultivated area (km^2)
Al-Kharj	Landsat-5	March 1993	820
	Landsat-5	March 1998	300
	Landsat-5	March 2001	505

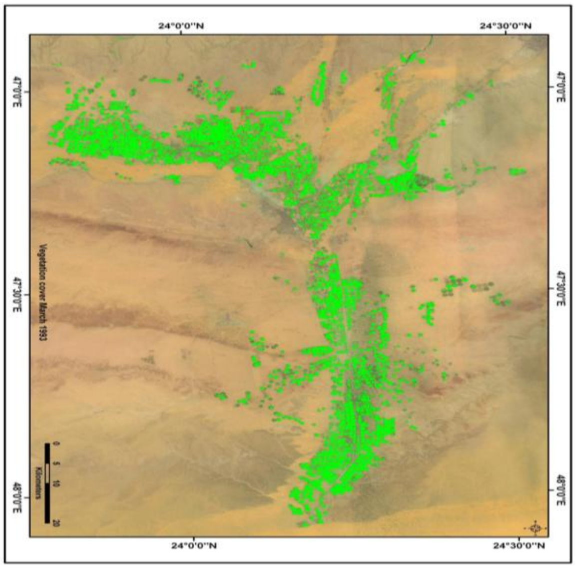

Figure 2. Satellite image map Landsat-5 for year1993. Green color show cultivated areas

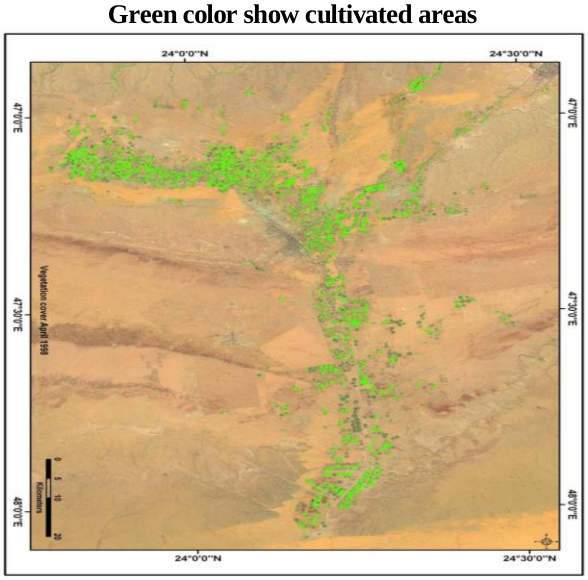

Figure 3. Satellite image map Landsat-5 for year 1998. Green color show cultivated areas

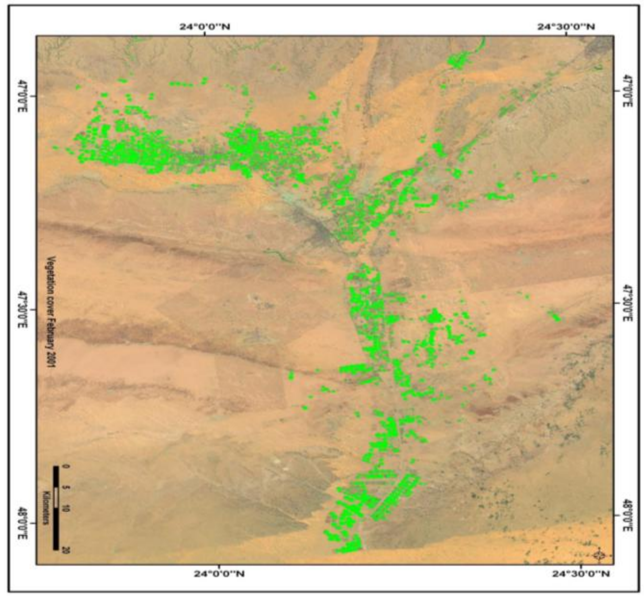

Figure 4. Satellite image map Landsat-5 for year 2001. Green color show cultivated areas

Remote sensing was used for identification of degraded areas. Technique used for surface features reflected by remotely sensed imagery and mapping soil surface conditions, such as salinity and sand sheet and sand dunes, are presence or absence of spectral absorption features. Simple identification and mapping of degradation features was performed by digital processing and analysis using a computer. Principal component and unsupervised classifications were used to identify the ground features which could be related to land degradation (Figure 5).

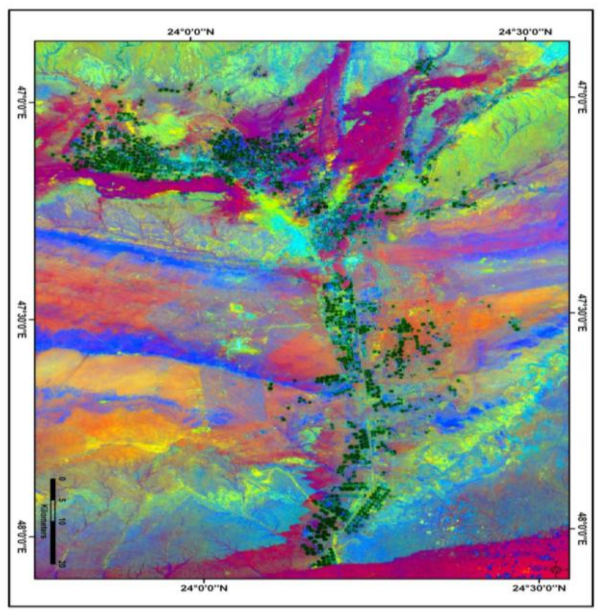

Figure 5. Satellite image map Landsat-5 obtained by PC for Al-Kharj area

Principal component analysis was done to Landsate-5 (2001), using 1, 2, 3, 4, 7 bands (Band 5 was excluded due to high gain). Result showed clearly the central pivots and some land forms. Characteristics of the rest area were difficult to trace by this technique.
To identify the various landforms in the studied area, unsupervised classification for Landsat-5 (2001) was applied. Several attempts were tried to identify the suitable number of taxonomic units. It was concluded that 10 units were more appropriate to show the cultivated area clearly with no overlapping with other units.

Verification by field trips (ground truth) indicated that there are three basic units and several sub-units in the area studied. The results revealed that the cultivated areas obtained by classification imagery was less than the area obtained through NDVI analysis, this may be due to interference within the classification units and the generalization in the image classification. Finally, information collected from staff belonging to ministry of agriculture, in the studied areas proved to be useful in identification of some degraded areas that were not identified through satellite images especially those suffered from deterioration of water quantities and quality.

Morphological Studies

Morphological studies indicated that, a wide variability of surface characteristics between the different types of land degradation i.e. white salt crust in salt affected soils, sand sheets, with varying thickness covering the surface of areas affected by sand creep. On the other hand, areas affected by wind erosion are characterized by the presence of gravel, stones and rock outcrops. Furthermore, the study also demonstrated a wide variability between the different types of degradations in other soil properties such as profile depth, texture, compaction and other morphological features related to land degradation such as carbonates, salts, mottles and gypsum.
Results of soil chemical and physical analysis plus field observations were used to identify the different types of land degradation in the studied area. Four major types were dominant and these includes; salinization (Cs), desert creep, erosion (Et) and in rare cases fertility decline. Salinization of the soil profile occurred mainly as a result of secondary salinization. Table 4 shows the salinity of irrigation water at different farms in the area.

Table 4. Salinity of irrigation water (K1, K4, K5 and K65) represents salt affected areas

Sample No.	Location	pH	EC (dS m^{-1})
1	K1	7.13	3.20
2	K2	7.51	1.50
3	K3	7.54	2.40
4	K4	6.51	2.92
5	K5	7.60	2.65
6	K6	8.23	0.37
7	K47	8.50	0.93
8	K65	7.56	4.68

High saline irrigation water caused accumulation of salts in the profile as depicted in (Table 5).

Table 5. Profile represents salt affected soils

Profile	Depth (cm)	SP (%)	pH	EC (dSm^{-1})
1	0-15	29.3	7.86	100
	15-50	36.7	8.28	10.6
	50-85	37.3	8.15	9.80

Other types of land degradation (water quantities and quality) were wide spread in the studied area. Three profiles representing salinization were selected in the study area. In general the obtained results showed that salinization, water quality and quantity, sand creep, and wind erosion represent the major types of land degradation in the studied area. The studied area was classified according to [15]. Results indicated that soil in the studied area falls under Entisols and Aridsols orders. Classification proceeded up to the sub great group. This classification slightly differs from previous classification conducted in the study area [16]. The difference is clearer in Aridisol order. In the present study a suborder Salids was identified [17, 18, and 19]. Formation of salt subsurface horizons led to the formation of these horizons and ultimately to the development of this suborder. Also Salids suborder includes a great group Aqusalids which indicates that the soils fall in a moist area as a result of capillary rise of water and accumulation of salts on the surface. This could be attributed to the presence of hard pan, shallow water table, topography and climate. Furthermore the present study showed a Gypsids subgroup belonging to Aridisols, characterized by a subsurface Gipsic horizon. The formation of this horizon is believed to be due to combined effect of parent material and soil management practices. This Gypsic hard pan could impair or reduce land productivity of the land. It is observed that in some parts of the studied area, efficient management practices led to improve the suitability class of the soil. Some soils were upgraded from not suitable (NI) or marginally suitable (S3) to moderately suitable (S2). Evaluation of the soils in the studied area showed that salinity, soil depth, texture and erosion and sand creep constitute the major limitation factors and negatively affect productivity of these soils.

Conclusions

Four major types of land degradation were dominant and these include salinization (Cs), sand creep, erosion (Et) and in rare cases fertility decline Comparing the current evaluation with previous ones, reflected that some soils were deteriorated to lower suitability classes or sometimes became unsuitable for cultivation. This happened as a result of presence of new limitations that were not observed in the former assessments. This development may reflect the unsuitability of management practices used. It seems that when adopting better land management practices that address the specific limitation could result in improvement in the suitability of the soil. This was demonstrated clearly in some parts of the studied area, specifically in Al-Kharj governorat**e** where some soils were upgraded from not suitable (NI) or marginally suitable (S3) to moderately suitable (S2). Nevertheless it should always be remembered that availability of good quality irrigation water, which the major limiting factor, is a perquisite for any improvement to occur.

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References

[1] H. Eswaran, “Soil resilience and sustainable land management in the context of Agenda 21,”. In: Soil Resilience and Sustainable Land Use, Eds. D.J Greenland and I. Szabolcs, 21–32. Wallingford: CABI, 1993.

[2] R. F. Misak, Al-Awadhi, JM., Omar, SO., Shahid, SA, “Soil degradation in Kabd, South western Kuwait city,”. *Land Degrad. Develop*, 2002, 13:403–415.

[3] Vilanculos, MF, “Interlinkages of soil and land use using remote sensing and GIS, a case study of the Ping Valley, Chiang Mai, Thailand, “. M.Sc. Thesis. ITC, Enschede, the Netherlands, 1994.

[4] Dudal, R, “ Paddy soils, . Int. Rice. Comm. News, 1975, I 7(2):19–27.

[5] FAO, “Guidelines: Land evaluation for rainfed agriculture,”. Soils Bull. 52. FAO, Rome, Italy, 1983.

[6] Beinroth, FH., Eswaran, H., Reich, P. F., E. Van den Berg, “Land related stresses in agro ecosystems,” . In: Virmani, S.M., J.C. Katyal, H. Eswaran, and I.P. Abrol. Eds., 1994. Stressed Ecosystems and Sustainable Agriculture. Oxford and IBH Publ. Co., New Delhi, India. 441 pp.

[7] Barth, HJ, “Desertification in the Eastern Province of Saudi Arabia,”. *Journal of Arid Environments*, 1999, 43: 399–410.

[8] Sirocko, F, “ The evolution of the monsoon climate over the Arabian Sea during the last 24,000 years,” *Palaeoecology of Africa*, 1996, 24, 53–71.

[9] Al-Abdela, SI., Sabrah, REA., Rabie, RK., agid, HMA, “ Evaluation of groundwater quality for irrigation in Central Saudi Arabia,” *Arab Gulf Journal of Scientific Research*, 1997, 15: 361–377.

[10] Karale RL., Seshagiri Rao, KV., Singh AN, “Evaluation of Landsat imagery for reconnaissance soil mapping,” presented at Andhra Pradesh Appreciation Seminar, New Delhi, 1978.

[11] Abdel-Hamid, MA., Sherestha, D. Valenzuela, C, “ Delineating, Mapping and Monitoring of Soil Salinity in the Northern Nile Delta (Egypt) using Landsat Data and a Geographic Information System, ” *Egypt, J. Soil Sci*., 1992, 32. No. 3, 463–481.

[12] Verma, KS.. Saxena, RK, Barthwal, AK., Deshmukh, SN, “ Remote sensing technique for mapping salt affected soils” *Int. J. Remote Sensing*, 1993, (15), No. 9.

[13] Metternicht, G.; Zinck, A, “ Remote Sensing of Soil Salinization: Impact on Land Management, “ CRC Press: Boca Raton, FL, USA, p. 377, 2008.

[14] Oldeman, LR., Hakkeling, RT, Sombroek, WG, ” World map of the status of human-induced soil degradation: an explanatory note,’ 2nd edition, International Soil Reference and Information Centre, United Nations, 1991 .

[15] Soil Survey Staff "Keys to Soil Taxonomy, 12th ed. USDA-Natural Resources Conservation Service," Washington, DC., 2014.

[16] Ministry of Agriculture and Water "The Land Resources" Ministry of Agriculture and Water, Land Management Department, pp. 1-33, 1995.

[17] Abdullah S. Modaihsh, Abdelazeem Sh. Sallam, Adel M. Ghoneim and Mohamed O. Mahjoub, "Assessing salt-affected degraded soils using remote sensing. Case study: Al-Qassim region, Saudi Arabia," *Journal of Food, Agriculture& Environment*.2014a, 12 (3&4): 383-388.

[18] Abdullah S. Modaihsh, Adel M. Ghoneim, Abdelazeem Sh. Sallam and Mohamed O. Mahjoub, "Soil Salinity, Sand encroachment and erosion as indicators of land degradation in Harad Center, Saudi Arabia, " *Journal of Remote Sensing and GIS*, 2014b, 2(1): 11-15.

[19] Bai, ZG., Dent, DL., Olsson, L Schaepman, ME "Global Assessment of land degradation and improvement 1: identification by remote sensing, "Report 2008/01, FAO/ISRIC–Rome/Wageningen, 2008.