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ORIGINAL ARTICLE

Environmental degradation assessment in arid areas: a case study from Basra Province, southern Iraq

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Abstract Evaluation of recent land degradation affecting Basra Province, Iraq, resulted in the identification of five prominent environmental degradation processes: desertification, secondary salinization, urbanization, vegetation degradation, and loss of wetlands. This analysis was carried out using '3S' technologies [remote sensing, geographic information system (GIS), and global position system], with the layers extracted and manipulated from available topographic, climatic, and soil maps, as well as satellite image (thematic mapping in 1990 and enhanced thematic mapping in 2003) and field survey data analyses. Rates of conversion were calculated and distribution patterns were mapped with the aid of a GIS. The results revealed that land use changes have affected the wider environment and accelerated land degradation, with severe damage located in southwestern Basra Province representing 28.1 % of the total area. Areas of high to moderate degradation characterize the rest of the south, representing 52.7 % of the total area; while the north of the study region is characterized by very low and low degradation levels accounting for 8.5 and 10.7 %, respectively. Iraq faces serious environmental degradation problems that must be addressed immediately; failure to do so will greatly compound the cost and complexity of later remedial efforts, with environmental degradation beginning even now to pose a major threat to human well-being, especially among the poor.

Keywords Environmental degradation · 3S technologies · Arid areas · Iraq

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Introduction

Environmental degradation and intensive deforestation due to industrialization and urbanization, war, and natural disasters such as flooding and drought caused by global warming are becoming increasingly common (Al-Dousari et al. 2000; Hui et al. 2008; Jabbar and Xiaoling 2006; Jabbar and Zhou 2011; Lindskog and Tengberg 1994; Sonneveld 2003; Symeonakis and Drake 2004). Analysis of land use/cover change (LUCC) is an important research field across the globe, being supported as a core project within the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) (Gray 1999; Hui et al. 2008; Johnson and Lewis 1995). LUCC is a very complicated process, affected by both natural and anthropogenic factors, although the former is generally dominant (Amissah-Arthur et al. 2000; Haboudane et al. 2002; Sujatha et al. 2000; Thiam 2003; Wessels et al. 2004). Research involving LUCC is a basic precondition of regional LUCC monitoring, driving factor analysis and even LUCC prediction (Eiumnoh 2001; Hoffman and Todd 2000; Symeonakis and Drake 2004; Taddese 2001). The landscape of Iraq has witnessed many changes during the past two to three decades (e.g., UNEP 2001), with current land use/cover percentages standing at arable land 13.12 %, permanent crops 0.61 %, permanent pastures 7.27 %, and other 79 %. Land under cultivation in Iraq, which is predominantly an agricultural country, represents around 12 % of the total area. Most of this land is in the region adjacent to the Tigris and Euphrates rivers (Al Janabi et al. 1988; Jabbar 2001).

Environmental degradation assessment requires the identification and inclusion of various indicators of desertification, both natural and man-made. Mouat et al. (1997) developed five indicators: drifting sand, grazing pressure, climatic stress, change in vegetation greenness, and weedy invasive species as a percentage of total plant cover. In contrast, Scoging (1993) identified the excessive exploitation of fragile ecosystems by human beings, the inherent fragility of resource systems, and adverse climatic conditions as causes of desertification. Assessment of degradation severity is, therefore, realistic only when both natural and anthropogenic factors are taken into consideration. Two natural factors that can significantly influence the severity of desertification are the percentage of existing vegetative cover and the amount of drifting sand. These two parameters are usually mapped using satellite imagery. For instance, visual interpretation of Landsat MSS images and aerial photographs enabled Gad and Daels (1986) to identify landforms indicative of desertification and to assess desert encroachment along the Nile Valley. Using historical aerial photographs and a Landsat MSS image, Omojola and Ezigbalike (1993) mapped the attendant land degradation processes and actions in the Sokoto-Rima River Basin in northwestern Nigeria, whereas a combination of coarse-resolution satellite data and fine-resolution Landsat MSS satellite data has proven ideal for the assessment of regional desertification status in the Patagonia region of South America (Del Valle et al. 1998; Liu et al. 2003).

In the present study, the mechanisms of environmental degradation were determined through analysis of natural settings in the study area and their evolution, as well as through field investigation. The objective of the field study was to identify and evaluate the present characteristics and processes of land degradation, analyzing 25 plots composed of 17 evergreen and 8 deciduous areas. Assessment of environmental degradation trends can be realistic only if anthropogenic factors such as population pressure are taken into account. Unlike natural factors, anthropogenic activities have not been commonly employed in assessing environmental degradation (Liu et al. 2003). Although Grunblatt et al. (1992) initially proposed to incorporate a human settlement indicator into their assessment scheme, it was not ultimately used to calculate the severity of degradation hazard. The successful implementation of a realistic environmental degradation assessment requires the integration of all identified indicators, a process which is readily achievable within a Geographic Information System (GIS). By integrating all data layers into a GIS, Mouat et al. (1997) identified landscapes characterized by varying levels of environmental degradation hazard, with simple ecosystem models also able to be included in the assessment process. The main objective of the present study was to explore an approach based on LUCC to quickly evaluate and map environmental degradation risks, using 3S technology and change detection techniques. Indeed, the emerging field of degradation assessment draws heavily from these three streams. The novelty of the present work is not so much the development of new conceptual domains, but rather integration across these three traditions.

This article is divided into four sections, following the introduction is a section discussing the employed materials and methods, a description of the study area, and the identification of environmental degradation processes. The subsequent section deals with a presentation of the results and an accompanying discussion, while the article ends with some concluding remarks as to the implications raised by the findings for environmental degradation control.

Materials and methods

Materials

Study area

The study region selected was Basra Province, Iraq (Fig. 1), representing a total area of 19,070 km^2 between longitude 46°60′–48°60′E and latitude 29°13′–31°29′N. The predominant soil of Iraq is considered sedimentary, especially in central and southern parts of the country. Basra Province is situated in a desert-type environmental zone with a monsoon climate; summers are very hot,

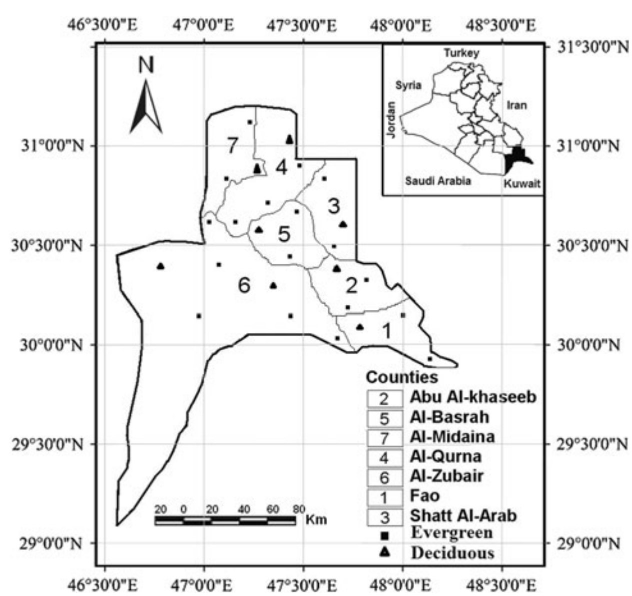

Fig. 1 General location of the study area, including county boundaries and plot sites

Table 1 Description of the prominent environmental degradation processes affecting the study area

Major processes and land-use subtypes	Description of degradation processes
Sandy desertification	Desertification is the conversion of land resources into sand, bare land, exposed rock and wasteland. Around one million hectares of central and southern Iraq is estimated to be suffering from desertification
Sand	
Bare land	
Infertile land	
Tundra	
Secondary salinization	Secondary salinization is the accumulation of electrolytes in the surface soil of arable land, transforming the latter resources into salinized land. Secondary salinization results from human activity, most commonly from poorly-managed irrigation
Salty land	
Wasteland	
Swamp land	
Unused land	
Urbanization	Expansion of non-agricultural land increases the pressure on agricultural land elsewhere, potentially prompting reclamation of marginal land areas and/or increasing environmental damage. In this sense, such expansion is an indirect land degradation process which affects Iraq's food security
Cities and towns	
Industrial land	
Military areas	
Mining land	
Docks	
Vegetation degradation	Vegetation degradation may result from a number of causes, including overgrazing, inadequate land reclamation and inadequate use of limited water resources. Vegetation degradation not only converts grassland to wasteland, but also induces undesirable pressure on adjacent areas
Date Palm	
Orchard	
Vegetable plots	
Natural grassland	
Loss of wetlands	Loss of marshland occurs where wetlands are transformed into bare land. Iraq's Ahwar regions (marsh) are ecological resources; they are fragile and need to be conserved. The marshlands have been declining for some time; in some cases they have been replaced by arable lands, in others they have been transformed into desiccated salinized land
Marsh	
Lake	
Reservoir and pond	
Beach	

especially July and August, with a mean temperature of 37.4 °C and a maximum temperature of 45 °C. The average potential evapotranspiration exceeds 2,450 mm/year, while average annual rainfall is less than 100 mm/year (Jabbar and Zhou 2011).

Remote sensing data

A multi-temporal Landsat (WRS2: 165/39, 166/38, 166/39 and 166/40, dated March 1990 and 2003) image dataset covering the study area was assembled and analyzed for LUCC as part of soil degradation indicator analysis. The spatial resolution of one pixel of the TM and ETM images was 28.5 × 28.5 m.

Ancillary data and software packages

A county-level topographic map, geological map, soil map, meteorological data, and all thematic layers were generated in a GIS environment at a scale of 1:250,000. The software packages employed in the present study were ERDAS (image processing), Arc/GIS (analysis and presentation of results), and SPSS (statistical analysis).

Methods

Image processing and field survey

Image processing included geometric correction in which ground control points were chosen, referencing a topographic map of scale 1:250,000. The land use/cover characteristics of the study area were classified into five categories: vegetable plots, sand, urban/residential land, water bodies, and unused land (bare land). Field data were collected in 2003–2004 from a total of 25 plots, comprising 17 evergreen and 8 deciduous vegetation areas (Fig. 1). The basic size of the plots was 15 × 15 m, established, subject to area conditions, using a Global Positioning System (GPS) receiver set into WGS84 at zone NUTM38 and later transferred to GIS and projected to the datum used for the satellite images (Almeida-Filho and Shimabukuro 2002; Jabbar et al. 2006).

Identification of environmental degradation processes

Environmental degradation is brought about by a number of ecological processes, including salinization, agrochemical pollution, soil erosion, and vegetation cover change (Thomas and Middleton 1993; Warren 2002). In the present study, the following five major environmental degradation processes were recognized as prominent: vegetation degradation, loss of wetlands, sandy desertification, urbanization, and secondary salinization. These processes are described in more detail in Table 1.

Environmental degradation indicators

Land degradation indicators were employed as a guide to evaluate the problem of environmental degradation in Basra Province. Four indicators have previously been identified as critical to the assessment of environmental degradation severity in the study area: vegetation cover, extent of drifting sand, urbanization rate, and population pressure (Table 2) (Liu et al. 2003). The first three are prime indicators of land degradation and are directly derivable from satellite imagery, whereas population pressure is an indirect and dynamic index. However, all are critical indicators of the environmental degradation hazard and its pattern of spatial–temporal change. Since realistic assessment is possible only with the assignment of appropriate weighting to the identified indicators, it was decided to categorize environmental degradation in the study area into four levels: severe, high, medium, and low (Table 2). The threshold for each rank of a given indicator was set in accordance with both the United Nations' indices for environmental degradation assessment and with actual field observation. The largest weight of 0.4 was assigned to vegetation cover because of its dominant role in the environment, while a similar weight was allocated to coverage of drifting sand (0.25) and population pressure (0.2). The lowest weight of 0.15 was given to the expansion rate of urban areas. The sum of all weights totaled 1 (Liu et al. 2003).

Table 2 Indices and weights for factors used in the assessment of environmental degradation

Indicator	Environmental degradation level				Weight
	Severe	High	Medium	Low	
Vegetation cover (%)	<10	10–25	25–40	>40	0.40
Drifting sand coverage (%)	>65	15–65	5–15	<5	0.25
Urbanization rate (%)	>5	2–5	1–2	<1	0.15
Population pressure (%)	>50	30–50	0–30	−30 to 0	0.20

Rates of environmental degradation change

Many models and indicators are available to analyze the magnitude, rate, and trend of land use and land cover change (LULC) (Al-Awadhi et al. 2005; Awasthi et al. 2002). As the present study aimed to use statistics to determine actual conversion rates of land degradation, the following equation was employed (Velazquez et al. 2003):

$$X = \left[1 - \frac{S_2 - S_1}{S_1}\right]^{1/n} - 1,$$

where X is the conversion rate of the environmental degradation process, S_1 is the degraded land area at time t_1 (1990), S_2 the degraded land area at time t_2 (2003), and n the difference in years between the two dates (i.e., 13). A transition matrix was also used to describe land conversion over the entire study period, while a transition probability index was adopted to conduct a trend analysis of landscape patch dynamics (Jia et al. 2004).

Results and discussion

Land use/cover change assessment

Table 3 summarizes the changes in LULC class coverage occurring within the study area between 1990 and 2003. Particularly evident is the decrease in areas covered by vegetation (24.1 %) and water (15.5 %), corresponding to an average loss of 342.2 and 97.4 km^2 year^{-1}, respectively. In contrast, areas of sand, unused land (bare land), and urbanization increased by 23.9, 17.6, and 19.9 %, respectively; this growth is likely due to the spread of desertification toward vegetation stands and farming plantations in southern Iraq. Anthropogenic causes of environmental degradation in the study area were identified via analysis and interpretation of field data, including current land cover and satellite images. Accordingly, the proportions of the main causes (i.e., land use/cover-related) are measured and presented in Table 3. The overall accuracy of classification analysis carried out using the ERDAS software program reached 97.89 and 95.93 % for 1990 and 2003 data, respectively.

According to the change detection report (Table 4), the area of desert sand increased by about 438.7 km^2 between 1990 and 2003, while vegetation coverage decreased by around 514.8 km^2. During the same period, the area of water bodies also fell (−228.4 km^2), whereas urban areas increased in size by 495.4 km^2. The main causes of these changes are likely wind erosion and anthropogenic activity. Barren land increased in area by 209.7 km^2 over the 13 years. Table 4 also shows that 514.9 km^2 of land classified as vegetation cover in 1990 was classified as sand in

Table 3 Calculated LULC class coverage totals obtained via satellite image analysis of the study area for the period from 1990 to 2003

LULC class	Area (km^2)				Change in area (km^2)	Percentage growth
	1990	(%)	2003	(%)		
Vegetation	5,110.8	26.8	4,595.9	24.1	−514.9[a]	−10.1[b]
Sand	4,119.1	21.6	4,557.7	23.9	438.6	10.6
Urban area	3,299.1	17.3	3,794.9	19.9	495.8	15.1
Unused land	3,146.5	16.5	3,356.3	17.6	209.8	6.6
Water bodies	3,184.7	16.7	2,955.9	15.5	−228.9	−7.2

[a] Area (km^2) 2003 − area (km^2) 1990

[b] Area (km^2) 2003 − area (km^2) 1990/area 1990 (km^2) × 100

Table 4 Change detection statistics report for the period 1990–2003 (km^2)

	Initial image 1990						
	Classes	Vegetation	Sand	Urban	Barren	Water	Class total
Final image 2003	Vegetation	3,102.2	779.1	313.8	265.2	135.5	4,595.8
	Sand	982.2	2,864.2	354.6	253.5	103.1	4,557.6
	Urban area	484.2	121.1	2,307.5	577.3	314.4	3,804.5
	Barren	445.4	261.3	216.1	1,809.4	223.9	3,356.3
	Water	96.6	93.3	117.1	241.2	2,407.6	2,956.1
	Class total	5,110.6	4,118.9	3,309.1	3,146.6	3,184.5	
	Class change	2,008.4	1,254.8	1,001.6	1,337.2	776.9	
	Difference	−514.8	438.7	495.4	209.7	−228.4	

2003, while 228.9 km^2 of land that had been classified as water body in 1990 was classified as urban/built-up or barren land in 2003. This data can be used to determine the extent of the changes taking place in land use/cover over time. Combined analysis of Tables 3 and 4 reveals the occurrence of significant changes in land use/cover, with the type of conversion taking place able to be identified. Between 1990 and 2003, areas of sand saw a relatively dramatic increase, with the class contributing the most to this change being vegetation cover. This pattern is suggestive of clearance and development. During the same time span, urban areas also increased in size. Again the majority of this change arose from the development of vegetated land; marshes saw a decrease in area of 228.9 km^2, with some converted to unused land (bare land) and others subject to urban development. Unsurprisingly, areas of vegetation were subject to a decrease in size, the largest fraction being converted to desert sand. In order to calculate the change detection accuracy, the final classified TM and ETM+ images were transferred into a single layer containing 10 different classes. As the accuracy assessment required intensive visual analysis, the sub-change categories of each land cover type were aggregated into a single change class (Zhou et al. 2008). Therefore, the 10 different classes were aggregated into five major subcategories, i.e., changed sand, changed vegetation, changed water, changed settlement, and changed unused land. The overall accuracy, kappa, producer and user accuracy values are presented in Table 5.

Table 5 Accuracy assessment of change detection

Classes	Producer accuracy (%)	User accuracy (%)
Vegetation cover	79.98	95.85
Sand cover	89.25	98.77
Urban area	74.93	82.61
Barren land	76.99	85.47
Water bodies	78.54	96.88
Overall accuracy = (209/256) = 81.64		
Kappa coefficient = 0.76		

Environmental degradation processes

The term ‘environmental degradation’ includes vegetation degradation and wetland loss, both of which are considered to be key components of terrestrial ecosystems since they are vital to land protection, biodiversity, hydrological and geochemical cycles, climate, and many other facets (Turner et al. 2000). Inappropriate land use changes affect an area’s ecological functions, potentially leading to a decrease in

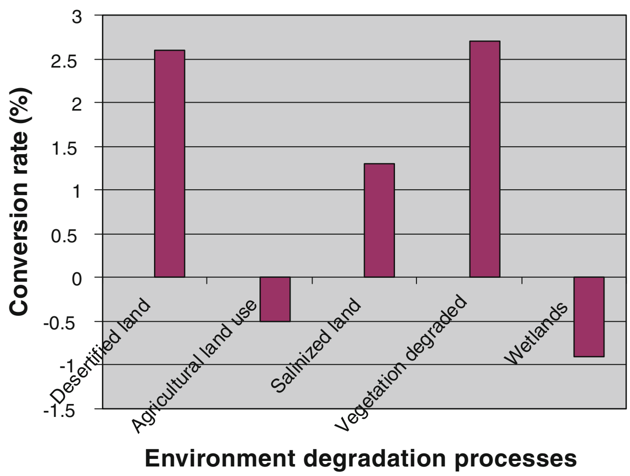

Fig. 2 Variation in conversion rate (*X*) among different land use types expressed as percentages

both productivity and biodiversity (Shahid et al. 1999). The calculated conversion rates of the environmental degradation process taking place in Basra Province between 1990 and 2003 are given in Fig. 2; in this figure the negative bars represent land types that decreased in extent, and the positive bars land types that expanded. Wetlands and agricultural land decreased in area by 743.8 km^2, a rate of 0.7 % per year. In contrast, desertified land, secondary salinization, and vegetation degradation increased by more than 0.8 % per year.

Figure 2 and Table 4 together reveal that the environmental conversion process occurring in Basra Province can be characterized in terms of four strands: (1) Degradation of vegetation cover accounted for more than 2.7 % (over 514.8 km^2) and wetland loss more than 0.9 % of the total land area (over 171.6 km^2); (2) Desertification affected more than 2.6 % of the total land area (over 495.8 km^2); (3) More than 0.5 % was affected by urbanization (loss of agricultural land use) (over 95.4 km^2), and (4) Some 1.3 % of the study area was converted into salinized land (more than 247.9 km^2) between 1990 and 2003. The increase in the area of degraded land was more than that of recovered land. The changes and spatial patterns of environmental degradation taking place during the study period will be analyzed in the following section.

Detection of vegetation change and wetland loss

One of the most frequently employed indexes of vegetation (Purevdorj et al. 1998), the Normalized Difference Vegetation Index (NDVI) is calculated as the difference between red (R) and near infrared (NIR) spectral reflectance measurements divided by their sum combination, i.e., NDVI = (NIR − R)/(NIR + R). NDVI values were used in the present study to develop grades of desertified land.

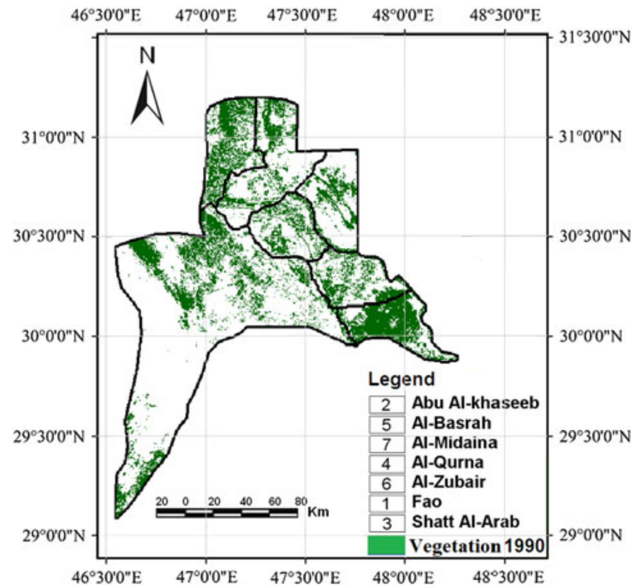

Fig. 3 Results of NDVI analysis performed on images of the study area for the year 1990

Figures 3 and 4 show that study area vegetation cover decreased from 5,107.8 km^2 in 1990 to 4,765.6 km^2 in 2003, representing a decline from 26.8 to 24.9 % of total land area. The area of wetlands also fell by 228.9 km^2 during the same period. Some marshes were converted to unused land (bare land), while others were subject to urban development. Figure 5 reveals that all counties in Basra Province experienced a decrease in surface water body area during the study period, with the highest and lowest change rates of 2.8 and 0.03 km^2 year^{-1} taking place in Al-Qurna and Fao counties, respectively. In Basra Province as a whole, the area of surface water bodies fell from 2,627.6 km^2 in 1990 to 2,530.2 km^2 in 2003. The observed decrease in most of the surface water bodies in the study area is likely the result of many factors, including a reduction in the flow of the Euphrates and Tigris Rivers from upstream countries; indeed, the use of river and lake water for irrigation in the study area is not possible without irrigation in the middle and southern parts of Iraq. Statistical analysis revealed a significant correlation between NDVI values and vegetation abundance (0.92) (Fig. 6).

A comparison of the 1990 and 2003 NDVI maps (Figs. 3, 4) suggests that large-scale vegetation cover change occurred in the study area during these 13 years. This change was likely a result of land salinization, agrochemical pollution, and soil erosion. In addition, many canals and reservoirs found in the 1990 images were not present in those from 2003; this disappearance could be another possible reason for the decrease in vegetation cover, although there were no data available to support this theory at time of writing. Although Figs. 3 and 4 provide an indication of changes in vegetation cover, decreases in

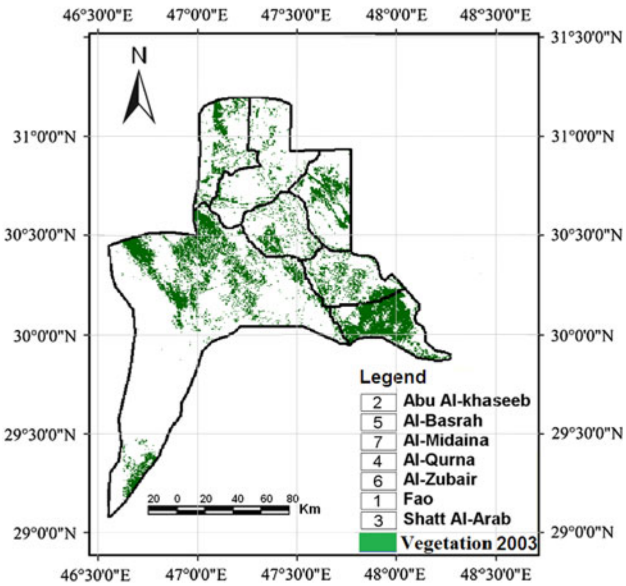

Fig. 4 Results of NDVI analysis performed on images of the study area for the year 2003

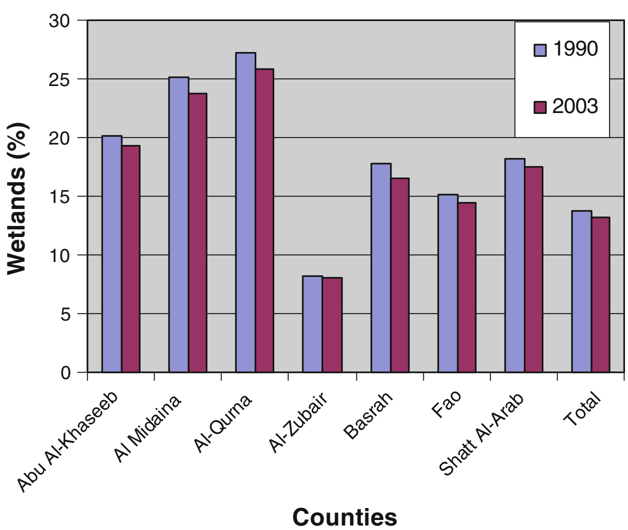

Fig. 5 Change in wetland area in the studied counties between 1990 and 2003

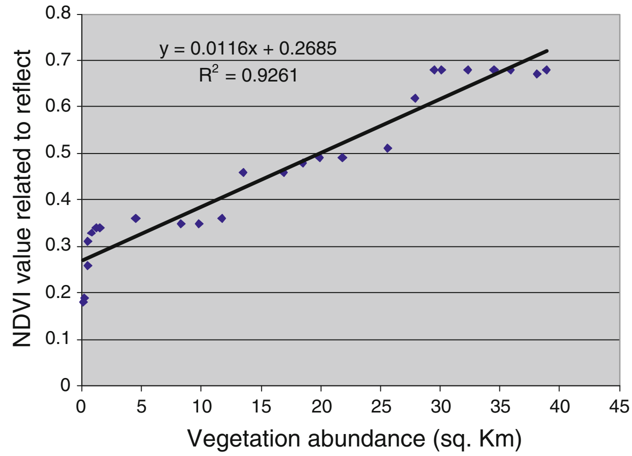

Fig. 6 Correlation equation for NDVI values and wetland area in southern Iraq

vegetation were observed at specific study area locations, indicative of poor land management. These areas are potentially at high-risk of future land degradation and should, thus, be subject to further investigation. The obtained results also suggest that enhancements to the employed analytical method could help to better monitor the condition and extent of salinization taking place on the margins of vegetated areas. Figures 3 and 4 represent a general estimation of vegetation cover change occurring in Basra Province, with the entire area presumed to be subject to vegetation degradation mainly as a result of anthropogenic activities and climatic variation. Between 1990 and 2003, 60.9 % of the region experienced a severe to high-level of vegetation change, with the remaining 39.1 % subject to moderate to low vegetation change, revealing the gravity of the problem in the study area. The present study represents the first to both examine vegetation change processes and monitor environmental changes taking place in southern Iraq using remote sensing, GIS, and GPS techniques. These effective and necessary methods were combined with expert opinions to obtain scientifically accurate results regarding changes in vegetation cover.

Drifting sand

To quantify sandy desertification, the Crust Index [CI = (Red band − Blue band)/(Red band + Blue band)] (Karnieli 1997) and Topsoil Grain Size Index [GSI = (Red band − Blue band)/(Red band + Blue band + Green band)] (Xiao et al. 2006) were used, along with the digital imaging techniques determining soil haematite content and crust or sand dune formation. These soil indices also depict the coarsening of topsoil directly related to fine sand content. However, the sand content data in the present study included both fine and coarse sand; as a result a significant correlation was found. GSI and CI values showed reasonable (and statistically significant) correlations of $r^2 = 0.73$ and $r^2 = 0.70$, respectively, computed directly from Landsat reflectance data.

More coarse topsoil was present in 2003 than the early 1990s throughout the study area (Table 6), indicating extensive expansion of drifting sand. The integrated sandy desertification assessment made by combining digital change detection analysis and satellite-derived soil indices revealed a 35 % difference in the desertified land in 1990. A total of 90 % of Basra Province was subjected to sandy desertification during the study period (1990–2003), with

Table 6 Variation in drifting sand coverage based on CI and GSI values for the period 1990–2003, obtained via analysis of Landsat TM and ETM+ images of Basra Province, Iraq

Study site	Area (km^2)	Drifting sand 1990		Drifting sand 2003		Increase in drifting sand area 1990–2003		Drifting sand rate km^2 year^{-1}
		(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	
Abu Al-Khaseeb	1,152	190.1	16.5	196.9	17.1	6.8	3.5	0.52
Al Midaina	989	22.7	2.3	23.7	2.4	1.0	4.4	0.07
Al-Qurna	2,612	88.8	3.4	91.4	3.5	2.6	2.9	0.20
Al-Zubair	11,618	3,732.6	32.2	4,152.7	35.7	420.1	11.2	32.31
Basrah	1,085	49.9	4.6	55.4	5.1	5.5	11.0	0.42
Fao	98	10.8	11.1	11.9	12.2	1.1	10.1	0.08
Shatt Al-Arab	1,516	24.2	1.6	25.7	1.7	1.5	6.1	0.34
Total	19,070	4,119.1	21.6	4,557.7	23.9	438.6	10.6	

the area of severely degraded land increasing by 19 %, moderately degraded areas increasing by 11 %, and the land area experiencing slight degradation expanding by 4 % (Table 6). Land degradation appeared to take place mostly in pastures, grassland areas, and dried water bodies. The annual rate of sandy desertification (slight, moderate, severe) was 10 % for the period 1990–2003. Variation in the extent of sandy desertification areas based on changes in GSI and CI values over time for each county in Basra Province is presented in Table 6, with data calculated on a pixel-by-pixel basis by subtracting 1990 values from those for 2003. It is apparent from these figures that the area of land subject to sandy desertification has increased, although the mean value of the indices in 1990 increased only slightly compared to the base year. 8.5 % of the area remained intact between 1990 and 2003, with the GSI and CI results showing that the main changes occurred along the western border of the province. The overall desertification trend was positive in all image-year combinations with the exception of 1990.

Built-up area assessment

A significant increase in Basra Province's urbanized areas between 1990 and 2003 was observed, with the annual rate of expansion in each county varying from 0.6 to 1.7 % (Table 7). As southern Iraq is considered a national economic and administrative center, the percentage increase in its total urban area of 19.7 % during the 13-year study period is perhaps unsurprising. Each county in Basra Province—Abu Al-Khaseeb, Al-Zubair, Basrah, Fao, and Shatt Al-Arab—experienced very high levels of urbanization, with percentage increases of 16.4, 17.5, 21.5, 19.3, and 13.2 %, respectively. These figures are a clear indication of the danger facing the region, given its fertility and agricultural value. The observed pattern is likely mostly related to socio-economic conditions. People tend to live where the administrations are concentrated, as well as in places where rural life is associated with a distinctive location strategy. As a result, such trends almost always have a direct effect on fertile cultivated land. Given these findings, a redistribution of administration and work opportunities must be considered in establishing new urban societies. Such a program should also focus on improving local education standards to improve awareness of environmental and population issues.

Salinization assessment

Table 8 displays the variation in area affected by various levels of salinity for each county in Basra Province between 1990 and 2003. The majority of the study area has been subject to land degradation, mainly as a result of anthropogenic activities and climatic variation, with 41.4, 24.1, 21.2, and 13.3 % of the region classified as experiencing none, slight, moderate, and high levels of land degradation via soil salinity risk, respectively. The data presented in Table 8 indicate a very clear and significant increase in the percentage of saline soils and a concomitant decrease in non-saline soils. While the latter covered around 60 % of the region in 1990, that percentage decreased to around 41 % in 2003. Levels of saline soils (ranging from slight to strong) also showed a significant increase during this period, with the area of strongly saline soils expanding from 1 to 7 %, and that of slightly saline soils by around 5 %. A global environmental hazard, soil salinization is also a severe problem for Iraq, adversely affecting crop yields and other forms of agricultural production. Salinity also negatively impacts water quality (rivers, streams and lakes), as well as the structural integrity of buildings, roads, and other infrastructure. Furthermore, ecosystems such as wetlands and forests are degraded as a result of increasing salinity levels. At the study locations, more than 50 % of land is adversely

Table 7 Calculated urban areas obtained via satellite image analysis of the study area for the period from 1990 to 2003

Study site	Total area (km^2)	Urban area (km^2)				Total increase (km^2)	Total increase (%)	Annual increase rate (%)
		1990	(%)	2003	(%)			
Abu Al-Khaseeb	1,152	161.3	14.0	187.8	16.3	26.5	16.4	1.3
Al Midaina	989	298.7	30.2	321.4	32.5	22.7	7.6	0.6
Al-Qurna	2,612	412.6	15.8	449.3	17.2	36.7	8.9	0.7
Al-Zubair	11,618	859.7	7.4	1,010.7	8.7	151.1	17.5	1.4
Basrah	1,085	342.8	31.6	416.6	38.4	73.7	21.5	1.7
Fao	98	10.1	10.6	12.1	12.3	1.9	19.3	1.5
Shatt Al-Arab	1,516	171.3	11.3	194.1	12.8	22.7	13.2	1.1
Total	19,070	3,280.1	17.2	3,756.8	19.7	476.7	14.5	1.2

Table 8 Variation in soil salinization coverage across the study area for the period from 1990 to 2003

County	County area (km^2)	Soil salinization area (km^2)		Increase (km^2)	Increase (%)	Environmental degradation rate/(km^2 $year^{-1}$)
		1990	2003			
Abu Al-Khaseeb	1,152	102.8	134.1	31.3[a]	2.7[b]	2.40[c]
Al Midaina	989	91.5	99.9	8.4	0.8	0.64
Al-Qurna	2,612	463.1	483.7	20.6	0.7	1.58
Al-Zubair	11,618	2,033.1	2,058.0	24.9	0.2	1.91
Basra	1,085	124.7	136.0	11.3	1.0	0.86
Fao	98	24.4	54.9	30.5	31.1	2.34
Shatt Al-Arab	1,516	362.3	385.1	22.8	1.5	1.75
Total	19,070	3,201.9	3,351.7	149.8	0.8	

[a] Soil salinization area (km^2) (2003) − Soil salinization area (km^2) (1990)

[b] Increase area (km^2)/county area (km^2) × 100

[c] Increase area (km^2)/13 years

impacted by dryland salinity, which damages a total of 20 % of the area each year. An estimated 6,579.1 km^2 of land in Basra Province is said to be at risk of soil salinity. As a result, agricultural production from farming industries such as grazing and cropping is diminished. Monitoring and managing salinity is, therefore, one of the greatest natural resource management challenges facing Iraq at national, state, and regional levels.

Environmental degradation via soil salinization increased rapidly between 1990 and 2003 in Basra Province, with almost all taking place on a lake or pond edge, river bank or flood plain. This pattern is likely a reflection of climatic warming, which resulted in potential evapotranspiration levels exceeding 2,450 mm/year and average annual rainfall <100 mm. Cultivation of original wetland is another major factor influencing land salinization. Large areas of wetland landscape suffered damage, with salinization and desertification interrupting material and energy cycles in a variety of ecosystems. Wildlife habitats are deteriorating in quality and even disappearing altogether, and as a consequence, biodiversity is seriously under threat. The decline in wetland area due to cultivation has gradually decreased the region's flood storage function, causing the frequency of downstream floods to increase. For the west of the study region, in particular, it is especially necessary to establish scientific and effective protection and recovery countermeasures. Establishing an adequate policy and legal system, adjusting the north to south water flow, dredging the surface water system, promoting circulation between surface and underground water, and setting up a wetland resource monitoring system, are all essential to restore the area's damaged wetlands.

Environmental degradation assessment

The five aforementioned environmental degradation processes and conversion rates were combined for the overall assessment of environmental degradation in Basra Province, based on calculated land use changes. Table 9 and Fig. 7 illustrate the distribution of environmentally sensitive areas in the study region. Analysis of these data reveals that the most sensitive areas to environmental degradation in Basra Province are found in the west, where the quality of soil, climate, and land management are low; these

Table 9 Categories of environmental degradation and the proportion of the study region belonging to each category

Class	Area (km^2)	%
Very low environmental degradation	1,620.9	8.5
Low environmental degradation	2,040.5	10.7
Moderate environmental degradation	3,604.2	18.9
High environmental degradation	6,445.6	33.8
Severe environmental degradation	5,358.7	28.1
Total	19,070	100

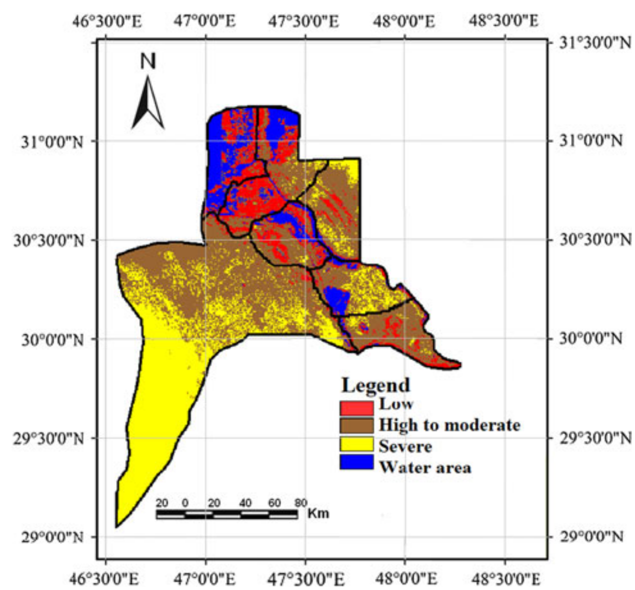

Fig. 7 Environmental degradation assessment for Basra Province

regions represent 28.1 % (5,358.7 km^2) of the total study area. Areas of high to moderate sensitivity are found in the south, accounting for 52.7 % (10,049.8 km^2) of the total area. In contrast, northern parts of the study region are characterized by very low or low sensitivity to environmental degradation, with these classes representing 8.5 and 10.7 % (3,661.4 km^2) of the total area, respectively. This reduced sensitivity is likely due to the presence of good vegetation cover and soil quality. The results of this study indicate that environmental degradation in Basra Province is derived from both natural and anthropogenic factors. GIS overlay of environmental degradation process layers interpreted from multi-temporal remotely-sensed images, in conjunction with field investigation, has revealed that the spatial extent of sandy desertified land in the region has drastically expanded during the 13-year study period (1990–2003).

Analysis of environmental degradation was carried out considering both natural (vegetative index, soil index, climatic index, drifting sand) and anthropogenic (land use change) factors. Most of the study locations were observed have been subject to high levels of environmental degradation. Furthermore, the region's overall sensitivity to environmental change worsened during the study period, with degraded areas accounting for 61.9 % of the total area in 2003. A clear northwest–southeast trend was determined regarding the spatial distribution of degradation within the study area; risk rose by an average of 40 % for all western parts of the Province between 1990 and 2003. Significantly, degradation risk increased considerably for those areas not previously considered highly vulnerable to degradation. Consequently, the disparity of environmental degradation hazard among the study locations has shrunk, with all of them at higher risk in 2003 than ever before. This accentuation of degradation is attributed to a variety of factors, including conflicts of (human) interest, increasing population pressure, limited land resources, and the fragility of the region's ecosystems. Inappropriate human activities such as the excessive exploitation of natural resources and mismanagement of land have, to a certain extent, contributed to the observed environmental destruction.

Conclusion remarks

Environmental degradation is a complex process. In this research, Normalized Differential Vegetation Index (NDVI), Crust Index (CI), and Topsoil Grain Size Index (GSI) were applied for detection of the vegetation and sand drifting change of soil surface, so as to monitor the environmental degradation process. This study has looked into the possibility of applying data collected by the land use variation survey to study the anticipated relationship between land uses/cover changes and environmental degradation in the south part of Iraq. The various databases were linked through GIS; the spatial distribution of land use changes produced realistic description of environment degradation in the study location. The research shows that south part of Iraq is quickly going through land use changes; the environment is adversely affected. Land degradation appears to be worsening; recently Basra Province experienced the most drastic undesirable changes in land use. These undesirable LUCCs might have been furthered by inadequate policy measures which encouraged land degradation. For example, large areas of cultivated land became occupied by non-agricultural users as a result of a sharply increased demand for real estate, economic development areas, and high-tech industrial parks. However, the Iraq Government has recognized that land degradation obstructs further sustainable development in the future. Although some fundamental strategies, as well as practical and economic practices have been implemented to combat land degradation and although achievements have been reached, under increasing population pressures and natural resource demand for rapid economic development, the situation is far satisfactory. Attempts should be made to adopt powerful approaches to control and rehabilitate negative changes to vegetation cover. Therefore, monitoring of the environmental change and regional planning in this region should become a priority.

This study recommended that there is a need to establish a professional arid environment center, which can be coordinated with government sectors and different universities in southern part of Iraq to solve the various environmental problems. It is also necessary to compare the case of Basra Province with other important cities in other developing countries that are experiencing similar forces of degradation processes. It is hoped that this application of the techniques of remote sensing and GIS to environmental research as demonstrated in this study can open up new arena of comparative research, so that a broad and full picture can eventually be unfolded to shed light over the pattern and processes of land use transformation in Iraq under environment degradation processes.

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