Remote Sensing and GIS Application in the Detection of Environmental Degradation Indicators

Hadeel A S1, Mushtak T Jabbar1,2, CHEN Xiaoling1,3

1. State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, 129 Luoyu Road, Wuhan 430079, China
2. Department of Soil and Water, College of Agriculture, University of Basrah (Iraq)
3. Key Laboratory of Poyang Lake Wetland and Watershed Research, Ministry of Education, Jiangxi Normal University, Nanchang 330022, China

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Abstract The main aim of this research is to highlight the environment change indicators during the last 20 years in a representative area of the southern part of Iraq (Basrah Province was taken as a case) to understand the main causes which led to widespread environment degradation phenomena using a 1:250000 mapping scale. Remote sensing and GIS's software were used to classify Landsat TM in 1990 and Landsat ETM+ in 2003 imagery into five land use and land cover (LULC) classes: vegetation land, sand land, urban area, unused land, and water bodies. Supervised classification and Normalized Difference Vegetation Index (NDVI), Normalized Difference Build-up Index (NDBI), Normalized Difference Water Index (NDWI), Normalized Difference Salinity Index (NDSI), and Topsoil Grain Size Index (GSI) were adopted in this research and used respectively to retrieve its class boundary. The results showed a clear deterioration in vegetative cover (514.9 km²) and an increase of sand dune accumulations (438.6 km²), accounting for 10.1, and 10.6 percent, respectively, of the total study area. In addition, a decrease in the water bodies’ area was detected (228.9 km²). Sand area accumulations had increased in the total study area, with an annual increasing expansion rate of (33.7 km²·yr⁻¹) during the thirteen years covered by the study. It is therefore imperative that Iraqi government undertake a series of prudent actions now that will enable to be in the best possible position when the current environmental crisis ultimately passes.

Keywords environment degradation; LULC; RS; GIS; classification; indices

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Introduction Environmental degradation caused by mankind’s exploitation and regional climate changes has long been a severe problem in the world, especially in the arid and semi-arid areas because of their ecosystems’ vulnerability.[1-7] During the last half-century, especially the last 20 years, drastic environmental degradation has occurred owing to wars, which have invoked society’s concerns. In the Basrah Province, like elsewhere in the world, environmental degradation can be classified into two categories, i.e. natural and anthropogenic. The former includes semi-tropical, arid, continental, and a monsoon climate. The latter involves population explosion and human activities.[8]
The formation of the fragile environment in southwest Iraq is a result of the long-term natural evolution, superimposed by human activities in recent times. Some of the main causes of environment degradation in Iraq are the overgrazing, misuse of the plant coverage, and sand dune formation. The movable sand dunes have direct effect on the infrastructure such as highways, railways, irrigation canals, agricultural soils, soil erosion, sand storms, as well as direct negative effect on the environment and human health. The continuous use of unsustainable practices, damage of the infrastructure during the War, and poor maintenance worsened by sanctions have caused a further soil and plant deterioration. Recent estimates showed that 75% of the total land in Iraq was arid and semiarid regions, and 50% of this land is subject to wind erosion, particularly in the south western part of the Iraq, where the degradation of land becomes a serious problem.

Baugh and Groeneveld quantitatively evaluated fourteen vegetation indices (VIs) using a Landsat TM dataset spanning 17 years over the San Luis Valley, Colorado, USA, to find the best VI for use in sparsely vegetated arid regions. His results showed that the NDVI offset index is effective for use in the study regions. Remote sensing has long been recommended for its potential role to detect, map and monitor degradation problems with spatial and spectral resolution and for the detection of degraded areas including their spread effects with time.

Raina, et al. found in his study that the cultivation of marginal areas and overgrazing of pastures has resulted in degradation of land. Accelerated wind erosion on sandy surfaces and water erosion on the shallow soils of piedmont areas are both common. Landsat Thematic Mapper sub-scenes have been used to map the type, extent and degree of degradation. In an area of over 5000 km², 42% was affected by wind erosion and 50% by accelerated water erosion. A quarter of the whole area needs urgent attention for soil conservation. Begzsuren studied the land degradation and desertification at Bulgan area, Mongolia, using a remote-sensing technique. He applied many soil and vegetation indices in his study. His results showed that the land degradation in the study area increased from 1990 to 2005, and 94% of the area is considered to be degraded to varying degrees.

The objectives of this study are to present an overview of environment degradation processes and to investigate the extent and magnitude of degradation in selected areas in the southern parts of Iraq as well as to define the causes of environment degradation.

1 Materials and methods

1.1 Materials

1.1.1 Study area

The study area (Basrah Province), located in the southern parts of Iraq, lies within longitude 46° 60′ to 48° 60′ E and from latitude 29° 13′ to 31° 29′ N with a total area of 19070 km² (Fig.1). To study the land use/cover change, the Districts of Basrah, Abu Al-Khaseeb, Fao, Al Midaina, Al-Qurna, Al-Zubair, and Shatt Al-Arab were selected as a study area. The Districts are situated in the southern parts of Iraq. Average population growth was estimated at 3.6% in the period 1990-2003. The soil of Iraq is considered as sedimentary soil, especially in the central and southern parts. The annual humidity is less than 50% and remains less than 30% during the daytime. The average evaporation exceeds 2450 mm per year with average annual rainfall less than 100 mm. The desert plants are adapted to these variations of meteorological factors and represent 66% of the total cover; these plants begin to grow immediately after rainfall and complete their life cycle by the end of the rainy period, and soon after, the temperature begins to rise. In recent years, along with the increase of population, economic development, improvement of investment

![Fig.1 General location of study area in the southern part of Iraq](image)
environment, Basrah Province has witnessed a rapid urbanization, which reverse has deeply affected ecological environment in the urban and rural regions.

1.1.2 Remote-sensing data

Multi-temporal Landsat (WRS2: 165/39, 166/38, 166/39, and 166/40) TM (dated March 1990) and ETM+ (dated March 2003) imageries remotely sensed datasets were assembled and analysed for land use as environmental degradation indicator analysis in the study area. The spatial resolution of one pixel of TM and ETM images was 28.5 m by 28.5 m.

1.1.3 Ancillary data and software packages

County-level topographic map, geological map, socio-economic, meteorological data, and all the thematic layers were generated in GIS environment at a scale of 1:250000. The software packages used for this study were ERDAS for image processing, Arc/Info for analysing and presenting the results. Statistical Graphics, NCSS, and Microsoft Excel were utilised in this research.

1.2 Methods

1.2.1 Pre-processing of images

The pre-processing for the dataset included image registration, radiometric calibration, and radiometric normalisation. Rectification and registration of TM and ETM+ imageries were based on control points collected from vector files of the large and small rivers at the study area using fifty ground control points (GCP). The remotely sensed dataset was geometrically corrected in the datum WGS84 and projection UTM N38 using the first order (linear) of polynomial function and Nearest Neighbor rectification resampling, which was chosen in order to preserve the radiometry and spectral information in the imagery. Image-to-image registration was done in order to register the ETM+ image (dated 2003) with geo-coded TM image dated 1990 (master image). The RMS error of the image-to-map was 0.35 to 0.45 pixel, while it was 0.15 to 0.20 pixel with image-to-image registration. The Landsat imageries were radiometric calibrated for sensor differences, converted into spectral radiance and normalized for illumination properties through differences in sun-elevation angle and sun-earth distance by recalculating the pixel values into at-satellite reflectance.

1.2.2 Post-processing of images

Two interaction goals followed in this study. In the first stage, remote-sensing techniques are used in evaluation of surface changes and determination of the type of land use classes. In the next stage, the area is evaluated for environmental change by using a prominent land degradation indicator method and GIS tools and then to analyse the impacts of land use/cover class expansion on environmental degradation.

The geometrically rectified and radiometrically calibrated TM, ETM+ bands 1, 2, 3, 4, 5, and 7 were used to derive the studied indices. Satellite-derived index images were produced to portray surface changes. In this research, two methods were used to retrieve class boundary, namely, supervised classification (a maximum-likelihood classification (MLC)) and indices. The five indices covered in this study were tested for vegetation changes; Normalized Difference Vegetation Index (NDVI), Build-up Index (NDBI), Water Index (NDWI), salinity Index (NDSI), and Topsoil Grain Size Index (GSI) were calculated on basis of the following equations, respectively:

- Normalized Difference Vegetation Index (NDVI):
The most common form of vegetation index is the Normalized Difference Vegetation Index or NDVI. The NDVI is basically the difference between the red and near-infrared band combination divided by the sum of the red and near-infrared band combination or:

\[
NDVI = \frac{(NIR - R)}{(NIR + R)}
\]

where \( R \) and \( NIR \) are the red and near-infrared bands.

- Normalized Different Built-up Index (NDBI):
To retrieve urban land from the Landsat imagery, a new index (NDBI) was used by this study's authors as follows, which is sensitive to the built-up area. NDBI was proposed by analyzing the spectral characteristics of different land use/cover types.

\[
NDBI = \frac{[(\text{band} 5) - (\text{band} 4)]}{[(\text{band} 5) + (\text{band} 4)]}
\]

where \( \text{band} 4 \) and \( \text{band} 5 \) of the Landsat TM or ETM+ images.

- Normalized Different Water Index (NDWI):
This study showed that the NDWI was developed to
delineate open water feature.\textsuperscript{[17]}

\[ NDWI = \frac{(\text{band}_4 - \text{band}_5)}{(\text{band}_4 + \text{band}_5)} \]  \hspace{1cm} (3)

where \text{band}_4 and \text{band}_5 represent the spectral bands of the Landsat images.

- Normalized Differential Salinity Index (NDSI): This index (NDSI) is just the reverse of the NDVI index for vegetation.\textsuperscript{[18]} The NDSI is basically the difference between the red and near-infrared band combination divided by the sum of the red and near-infrared band combination, or the algorithm used was:

\[ NDSI = \frac{[\text{band}_3 - \text{band}_4]}{[\text{band}_3 + \text{band}_4]} \]  \hspace{1cm} (4)

where \text{band}_3 and \text{band}_4 represent the spectral bands of the Landsat images.

- Topsoil Grain Size Index (GSI): Topsoil Grain Size Index (GSI) was developed based on the field survey of soil surface spectral reflectance and laboratory analyses of soil grain composition.\textsuperscript{[18]} GSI found has close correlation to the fine sand or clay-silt-sized grain content of the topsoil in sparsely vegetated arid land of Inner Mongolia, China. A high GSI value corresponds to the area with high content of fine sand in topsoil or low content of clay-silt grains. The GSI can be simply calculated by

\[ GSI = \frac{(R - B)}{(R + B + G)} \]  \hspace{1cm} (5)

where \(R\), \(B\), and \(G\) are the red, blue, and green bands of the remote-sensing data, respectively. GSI value is close to 0 in the vegetated area, and for water body, it is a negative value.

1.2.3 Statistical analysis

Analyzing impacts of urban, sand, and bare lands expansion on land use/cover change using the statistical data of Basrah Province in recent years, effect of classes’ expansion on environmental changes was analyzed.

2 Results and discussion

2.1 Assessment of land surface changes

Based on remote-sensing images combined with field investigations, several environment change indicators were defined in this study. Most of these indicators are attributed to the combination of population growth, economic development, drought periods, and the military activities in 1990-2003. This is in accordance with the studies of Jabbar.\textsuperscript{[8]} These multiple functions are the main cause of environment degradation on the vulnerable resources of Basrah Province’s desert ecosystem. The inherent fragility of the soils, vegetation covers and micro-relief of the desert surface exacerbates this combination of causes.

Fig.2 summarizes the various land use/cover typologies and the land use dynamics during the period 1990-2003. The data reveal that during the 20-year period, several land use changes occurred; in particular, a decrease in areas covered by vegetation (24.1%) and water (15.5%) was highlighted, corresponding to an average loss of 342.2 and 97.4 km\textsuperscript{2}·yr\textsuperscript{-1}, respectively. On the contrary, sand lands (sand dunes), unused land, and urbanization increased by 23.9%, 17.6%, and 19.9% respectively; such increase is due to the evolution of desertification towards vegetation stands and to the farmer plantations in the south parts of Iraq. The human causes of environment degradation in the studied areas are identified on the basis of analysis and interpretation of field data, including current land uses and satellite images. Accordingly, the proportions of the main causes (i.e. land-use-related) are measured and presented in Fig. 2.

![Fig. 2 (LULC) classes monitored from satellite image for the study area](image-url)
this change came from the development of vegetation land into an urban class. Marshes saw a decrease 228.9 km² in size. Some of the marshes converted to unused land, while some of it was converted to urban.

Finally, vegetation areas saw a decrease in size. The largest portion was converted to sand land, with another portion converted to barren, and a significant portion was developed into urban areas.

### Table 1  LULC cover transition matrix (km²)

|            | Vegetation | Sand    | Urban | Barren | Water |
|------------|------------|---------|-------|--------|-------|
| 1990 Totals| 5110.8     | 4119.1  | 3299.1| 3146.5 | 3184.7|
| Vegetation | 3107.2     | 769.1   | 318.8 | 270.2  | 130.5 |
| Sand land  | 972.2      | 2869.2  | 349.6 | 258.5  | 108.1 |
| Urban area | 489.2      | 116.1   | 2302.5| 567.3  | 319.4 |
| Barren     | 440.4      | 266.3   | 221.1 | 1814.4 | 213.9 |
| Water      | 101.6      | 98.3    | 107.1 | 236.2  | 2412.6|

### 2.2 Identification of environment degradation processes

Environment changes identified from NDVI, NDBI, NDWI, NDSI, and GSI indices were computed and obtained for the Landsat TM (1990) and enhanced TM Plus (ETM+ (2003)) satellite images. Environment degradation is brought about by a number of ecological processes including depletion of salinization, soil erosion, and vegetative degradation as a result of vegetation cover change.\[^{20,21}\] In this study, five major environment degradation processes were recognized as prominent:

- **Deterioration of Vegetation Cover**: In comparison between the vegetative cover area for each county during the two years 1990 and 2003 by application of NDVI, a high decrease in the vegetative cover in most of the studied counties is observed. Al-Zubair, Al-Qurna, and Shatt Al-Arab registered the worst situation and the highest decline (Fig. 3 and Fig. 4) in the vegetative cover during the mentioned years. They were 127.8, 75.7, and 44.1 km² of the total area of each county, respectively. The results reveal that the vegetation degradation, which is mainly due to overgrazing and human activities, is a major component of the land degradation problem in Basrah Province. Human activities including the Gulf War (1990-1991) and recreation activities and surface-gravel quarrying have left many scars on the fragile desert ecosystem of Basrah Province, such as compaction of topsoil, disruption of local relief and soil disturbance. On the other hand, most of the productive lands in Basrah Province face serious environmental constraints because of salinization effects.\[^{8}\] The war damage inflicted on the infrastructure and the pollution from oil-well fires has further exacerbated these constraints. Unfortunately, very little has been done on soil reclamation and management.
Urbanization process: By analyzing the urban boundaries of Basrah Province counties in 1990 and 2003 resulted from NDBI, we can find that during the 13 years, study location has witnessed a rapid urban expansion. From 1990 to 2003, the urban area has added 476.7 km², from 3280.1 km² to 3756.8 km². The average increase rate was 1.2% per year, and the rate of increase ranged from 0.6% to 1.7% (Fig.5). The causes of urban expansion in the center and the south Basrah Province were the high and new technological industry zone, Basrah Province economical, and technological development zone which are newly located in these regions, respectively. Because of large-scale construction of the development zone, large-scale constructions of infrastructures have made urban expansion to develop rapidly.

Wetlands Loss: The major environmental degradation indicator identified in the arid environment of study location is water surface change. Results of NDWI clarified a significant decrease in the area covered by water bodies during the study period from 1990 to 2003. Water bodies at Al-Qurna, Basrah, and Al Midaina counties suffered significant loss in the areas covered by water. The measured reduction in water cover was 36.5, 14.1, and 13.8 km², respectively (Table 2). The results showed an increase in the negative change in the whole study area. The decrease in most of the surface water bodies of the study area refers to many reasons; the areas occupied by the marshlands have been affected the most, with the largest changes occurring in the 1990’s with the implementation of the Southern Anatolian Project in Turkey and the rerouting of the Tigris and Euphrates Rivers in Iraq around the marshlands using a complex system of diversion canals, such as to the decrease in the flow of the Euphrates and Tigris Rivers from the upstream countries.[22] Also, the use of rivers and lake's water for the irrigation in the study area due to the agriculture is not possible without irrigation in the middle and southern parts of Iraq. The statistical analysis showed that this index (NDVI) has a significant correlation with water bodies’ positive change (0.94).

| Study site          | Study area (km²) | Water bodies 1990 (km²) | Water bodies 2003 (km²) | Water bodies 1990-2003 (km²) | Water bodies change (km² • yr⁻¹) |
|---------------------|------------------|-------------------------|-------------------------|-----------------------------|---------------------------------|
| Abu Al-Khaseeb      | 1152             | 232.7                   | 222.3                   | −10.4²                    | −0.45³                          |
| Al Midaina          | 989              | 248.2                   | 234.4                   | −13.8                      | −0.55                            |
| Al-Qurna            | 2612             | 710.4                   | 673.9                   | −36.5                      | −0.51                            |
| Al-Zubair           | 11618            | 952.6                   | 941.1                   | −11.5                      | −0.12                            |
| Basrah              | 1085             | 193.1                   | 179.0                   | −14.1                      | −0.73                            |
| Fao                 | 98               | 14.7                    | 14.2                    | −0.5                       | −0.34                            |
| Shatt Al-Arab       | 1516             | 275.9                   | 265.3                   | −10.6                      | −0.38                            |
| Total               | 19070            | 2627.6                  | 2530.2                  | −97.4                      | −3.7                            |

Note: (a: Water bodies area (km²) (2003) − Water bodies area (km²) (1990); (b: Decrease area (km²) / County area (km²) × 100; (c: Decrease area (km²) / 13 years.

Soil Salinization: Salinization has long caused serious damage to arable land and grasslands in middle and south parts of Iraq. Inadequate land reclamation and misuse of water resources have been the main reasons of secondary salinization. According to a soil survey study and imageries remotely sensed dataset (NDSI) index, the land degradation areas in 2003 are larger than those in 1990: Abu Al-Khaseeb (2.40 km² • yr⁻¹) and Fao (km² • yr⁻¹) area is more than Al Midaina (0.64 km² • yr⁻¹) and Basrah (0.86 km² • yr⁻¹).
The declining vegetation is conspicuous in 2003 and larger than that in 1990 in the Abu Al-Khaseeb and Fao areas. However, extended environment degradation was clearly found in the study location (Fig. 6). The results of the statistical analysis showed that the saline area has a significant correlation with vegetation cover negative change (0.92).

![Fig. 6 Soil salinization coverage percentages during the period from 1990 to 2003 derived from NDSI](image)

- **Wind Erosion and Aeolian Deposits:** Wind erosion is considered the major cause of irreversible land degradation in the arid environment of Basrah Province where dry, noncohesive sandy soils, poor vegetation cover, strong wind, and hyper-arid conditions prevail. It was found through the application of GSI for the sand land surface in the study area and it is effective and efficient in isolating and highlighting the presence of sand land and drifting sands. The GSI was specifically designed for using Landsat TM/ETM+ data sets. Obtained results of GSI gave a good impression and promising ability on its capability for identifying and highlighting the sand area accumulations at the study area. The results indicated an obvious increase (Table 3) of the sand area accumulations at the study area during the thirteen-year study period, especially in the west part of Basrah Province (Al-Zubair County), which got the highest increase in the sand accumulation area at the study region during the years from 1990 to 2003, that was 420.1 km$^2$. Environmentally, wind erosion has both on-site and off-site impacts. The on-site impacts include the loss of topsoil by deflation and terrain deformation by hollows, granule ripples, blowout and dunes. The off-site impacts include sand and dust storms, and sand encroachment on various facilities. During the summer, the Al-Zubair County, for instance, provides an influx of sand and dust to Basrah City, located at 15 km to the southwest of Al-Zubair area, producing environmental and health problems there.

| Study site       | Area (km$^2$) | Drifting sand 1990 | Drifting sand 2003 | Drifting sand 1990-2003 | Drifting sand rate (km$^2$ yr$^{-1}$) |
|------------------|---------------|--------------------|--------------------|------------------------|-------------------------------------|
| Abu Al-Khaseeb   | 1152          | 190.1              | 196.9              | 6.8                    | 0.52                                |
| Al Midaina       | 989           | 22.7               | 23.7               | 1.0                    | 0.07                                |
| Al-Qurna         | 2612          | 88.8               | 91.4               | 2.6                    | 0.20                                |
| Al-Zubair        | 11618         | 3732.6             | 4152.7             | 420.1                  | 32.31                               |
| Basrah           | 1085          | 49.9               | 55.4               | 5.5                    | 0.42                                |
| Fao              | 98            | 10.8               | 11.9               | 1.1                    | 0.08                                |
| Shatt Al-Arab    | 1516          | 24.2               | 25.7               | 1.5                    | 0.34                                |
| Total            | 19070         | 4119.1             | 4557.7             | 438.6                  | 10.6                                |

### 2.3 Environmental degradation assessment

In Table 4, we have the general estimation for environment degradation in the Basrah Province. It is supposed that all the area is subject to environment degradation as we mentioned previously, mainly by anthropogenic activities and climatic variation. So we conclude that 61.9% of the land area in the Basrah Province had severe environment change, 18.9% had moderate environment change, and 19.2% had slight environment change. Without a doubt, these results show the gravity of vegetation cover change as a problem in the Basrah Province. Change to environment takes place widely in the study location area, and it has a great impact on local peoples’ livelihood and socio-economic development. Although some fundamental strategies and practical and economic practice have been implemented to combat environ-
ment change, and achievements have been reached, it is still a tough task in the southern part of Iraq (Basrah Province) under the pressure of increasing population and demand of natural resources for rapid economic development. Attempts should be made to adopt powerful approaches to control and rehabilitate change to land use/cover. Therefore, the monitoring of the environmental change and regional planning is needed in this region. In the southern part of Iraq, it is the first time to study land use/cover change processes and monitor the environment changes using remote sensing, GIS and GPS technique. It is an effective and necessary method combining RS and GIS technique with experts’ knowledge for change to environment studies, based on geo-information technology support, to widely use expert’s knowledge in the study and to obtain scientific results.

### Table 4  Environment degradation grades from 1990 to 2003

| Location       | Slight | Moderate | Severe | Very severe |
|----------------|--------|----------|--------|-------------|
|                | Area (km²) | Proportion (%) | Area (km²) | (%) | Area (km²) | (%) | Area (km²) | (%) |
| Abu Al-Khaseeb  | 214.2 | 18.6 | 206.2 | 17.9 | 399.7 | 34.7 | 314.5 | 27.3 |
| Al Midaina      | 293.7 | 29.7 | 214.6 | 21.7 | 337.2 | 34.1 | 143.4 | 14.5 |
| Al-Qurna        | 162.7 | 6.2 | 538.1 | 20.6 | 830.6 | 31.8 | 710.5 | 27.2 |
| Al-Zubair       | 1243.1 | 10.7 | 1847.3 | 15.9 | 3555.1 | 30.6 | 4867.9 | 41.9 |
| Basrah         | 209.4 | 19.3 | 201.8 | 18.6 | 413.4 | 38.1 | 259.3 | 23.9 |
| Fao            | 18.2 | 18.6 | 17.5 | 17.9 | 32.8 | 33.5 | 29.3 | 29.9 |
| Shatt Al-Arab   | 265.3 | 17.5 | 295.6 | 19.5 | 503.3 | 33.2 | 453.3 | 29.9 |
| Total          | 3661.4 | 19.2* b | 3604.2 | 18.9 | 6445.6 | 33.8 | 5358.7 | 28.1 |

Note: * b (Slight) represents total newly increased desertified areas (km²) / total area (km²) × 100.

### 3 Conclusion

The research highlighted that land use dynamics is a useful indicator for areas threatened by environment degradation, being it closely related to anthropic pressure. This is particularly true in the south part of Iraq areas where progressive loss of vegetation cover, also due to wars, irrational tillages and overexploitation of available resources contributed to favor land degradation processes. Basrah Province faces a number of land-degradation interventions of varying degrees such as soil erosion by wind, deterioration of vegetation cover, wetlands loss, and soil salinization. Based on the percentage of land cover change and physical properties of the soil, four classes of environmental degradation, namely, very severe, severe, moderate and slight, are identified. The average percentage distributions of theses classes in the studied areas are found to be 28.1, 33.8, 18.9 and 19.2 per cent for the very severe, severe, moderate and slight classes, respectively. Development of a national action programme to control environment degradation is strongly recommended at this stage where moderate-to-severe environment degradation prevails in most of the land surface of Basrah Province. Introducing environmentally sound, socially acceptable and economically feasible land-use systems, especially for grazing and reclaiming polluted or salinized soils should be urgently attended to by the Iraqi government. A sustainable development for rural areas must allow the recovery and protection of affected and threatened areas by providing aid for farmers no more linked to the number of grazers. This can contribute to reduce pressures on low productive lands threatened by desertification with particular reference to common lands.

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