Journal of Earth Science, *Vol. 23*, *No. 6*, *p. 881–891*, *December 2012* *ISSN 1674-487X*
Printed in China
DOI: 10.1007/s12583-012-0299-5

Assessment of Soil Salinity Risk on the Agricultural Area in Basrah Province, Iraq: Using Remote Sensing and GIS Techniques

Mushtak T Jabbar*
School of Environmental Science & Engineering, *Huazhong University of Science & Technology*, *Wuhan* 430074, *China*; *Department of Soil and Water*, *College of Agriculture*, *University of Basrah*, *Karmat Ali* 61004, *Iraq*
Jingxuan Zhou (周敬宣)
School of Environmental Science & Engineering, *Huazhong University of Science & Technology*, *Wuhan* 430074, *China*

ABSTRACT: This study presents an integrated study of expansion process of salinized land in Basrah Province, a typical salt-affected area in southern parts of Iraq, by using geo-information techniques. Satellite images (Landsat TM 1990) and thematic maps (ETM 2003) were used to provide comprehensive views of surface conditions such as vegetation cover and salinization detection. With ERDAS software, the normalized differential salinity index (NDSI) and salinity index (SI) were computed and then evaluated for soil degradation by salinization. ARC/INFO software was used along with field observation data (global positioning system) for analysis. During the past 13 years, the salinized land in study area increased by 6 579.1 km^2 and in 2003 covered 34.5% of the total area; in the meantime, vegetation cover has decreased by 4 595.9 km^2 and in 2003 covers only 24.1% of the study area. Environmental changes show that, between 1990 and 2003, 37.5% of vegetation cover and 45.9% of marshlands were transformed into salty meadow and wet salty crust, respectively. In addition, there was 16.6% of sand lands converted into dry puffy salty crust. Results using spatial analysis methods showed that 7 894.9 km^2 (41.4%) of land had no risk of environment degradation by soil salinity, 4 595.9 km^2 (24.1%) had slight risk, 4 042.8 km^2 (21.2%) had moderate risk, and 2 536.3 km^2 (13.3%) of the total land area was at a high risk of environment degradation by soil salinity. In conclusion, the study area was exposed to a high risk of soil salinity.

KEY WORDS: environmental degradation, soil salinity risk, remote sensing, GIS, Iraq.

INTRODUCTION

Nowadays, soil salinity is an increasing environmental problem throughout the world. The global extent of primary salt-affected soils due to natural factors is ~955 M·ha, i.e., ~7% of the Earth's continental extent, whereas secondary salinization as a consequence of human activities affects some 77 M·ha

This study was supported by the Basrah University, Iraq and the Outstanding Doctorate Thesis Foundation of Huazhong University of Science and Technology, the Youth Chenguang Project of Science and Technology of Wuhan City of China (Nos. 20015005037 and 20055003059-34), and the Natural Science Foundation of Hubei Province (No. 2005ABA047).
*Corresponding author: mushtak1967@yahoo.com

Manuscript received November 5, 2011.
Manuscript accepted January 7, 2012.

(Metternicht and Zinck, 2003). Salt excess in soils has detrimental effect on crop yields and agricultural production due to poor land and water management and results in substantial losses of arable soils, especially in the arid and semiarid areas (Cayuela et al., 2001). Furthermore, salinity also affects other major soil degradation phenomena such as soil dispersion, increased soil erosion, and engineering problems (Metternicht and Zinck, 2003). Land use/cover changes play a pivotal role in environmental and ecological changes and furthermore contribute to global change (Lichtenberg and Ding, 2008; Lambin et al., 2001). Changes in land use and land cover have important consequences for natural resources (Awasthi et al., 2002), and they significantly affect the key aspects of the Earth's system functioning. These changes are the primary source of soil degradation (Jabbar and Chen, 2006; Collado et al., 2002; Jabbar et al., 2002) and affect the ability of biological systems to support human needs (Vitousek et al., 1997). Salinity problems have a large impact especially in semiarid regions because these areas with harsh climatic conditions are under high pressure to supply the required food and fiber for their rapidly increasing population. This pressure results from changes in land use, which is mainly due to the common policy of agricultural intensification (Farifteh et al., 2006).

Remote sensing is one of the key tools in monitoring local, regional, and global environmental issues. More recently, much attention has been paid to spatial analysis due to the merging of geographic information system (GIS) and satellite images for environmental research and applications. The conventional means are, however, difficult and laborious due to vagaries of the weather. It is prudent to use such an emerging technique with an emphasis to its application in semiarid areas (Verbeiren et al., 2008; Jabbar et al., 2004; Jia et al., 2004; Jabbar, 2003; Shen and Kheoruenromne, 2003; Dymond et al., 2001). Remote sensing can significantly contribute to detecting salt-related surface features and has been used for soil salinity mapping in recent papers. However, quantitative results of soil salinity from remote sensing applications are difficultly achieved without plenty of auxiliary data such as groundwater depth and groundwater mineralization rate, which are insufficient and difficult to obtain, especially in remote arid area (Metternicht and Zinck, 2003; De Jong, 1994). In general, three different non-unique techniques (remote sensing, fieldwork, and laboratory studies) can be used to identify, detect, and predict the areas affected by salts. Among these, remote sensing data and techniques have been widely used to map salt-affected areas (Farifteh et al., 2006; Dehaan and Taylor, 2003; Verma et al., 1994; Hick and Russell, 1990; Goetz and Herring, 1989; Goetz et al., 1985). The presence of salts at the terrain surface can be detected from remotely sensed data either directly on bare soils, with salt efflorescence and crust, or indirectly through vegetation type and growth, as these are controlled or affected by salinity (Mougenot et al., 1993).

The specific objectives of this study are (1) to monitor land cover patterns and to detect changes that occurred in the south part of Iraq, (2) to demonstrate the effectiveness of combining remote sensing data in assessing salinization, and (3) to analyze possible factors influencing soil salinization and to provide useful information for improving grassland and cropland management practices and restoring the vegetation in this region.

MATERIALS AND METHODS

Study Region

In order to study the soil salinity impacts of environmental degradation, Basrah Province has been selected as a study area. Geographically, Basrah Province is situated in the southern part of Iraq at the northwestern corner of the Arabian Gulf, within longitude 46°60′E–48°60′E and from latitude 29°13′N–31°29′N with a total area of 19 070 km^2 (Fig. 1). Average population growth was estimated at 3.6% in the period 1990–2003. Geomorphologically, the soil of study location is considered as flat sedimentary soil and it is located on the downwind side of the high deflational area of the Mesopotamian flood plain in southern Iraq. During summer, the prevailing northwesterly wind, which reaches a maximum of 30 $m \cdot s^{-1}$ in June, transports sands and finer particles from this flood plain towards Basrah. Climatically, like most parts of the Arabian Peninsula, a desert-type environment with scanty rainfall and hot dry weather characterizes the climate of Basrah. Summer is very hot, especially in July and August, with mean temperatures of 37.4 ℃ and maximum mean temperatures of 45 ℃. The average evaporation exceeds 2 450 mm/a with an average annual rainfall of <100 mm/a. In the western parts of Basrah Province, the scarcity and irregularity of rainfall, the availability of sand supply areas, and the prevalence of strong northwesterly winds significantly influence the stability and productivity of the desert ecosystem. For more than two decades, the vulnerable terrestrial environment of Basrah Province has been subjected to intensive pressure from urbanization over utilization of resources and war activities. Several indicators of environment degradation have been recognized in Basrah Province (Jabbar, 2001).

Methods

Fieldwork and laboratory studies

The fieldwork, concurrent with the satellite acquisition over the study area, includes soil sampling, groundwater table, and measurement of vegetation plots. The sampling spots were chosen to span the range of dominant surface features using 1 : 250 000 topographical maps and located by global positioning system (GPS). Biomass and coverage percentage of 30×30 m plots were measured. Twelve randomized soil samples were gathered on the profiles from 0 to 30 cm from each county polygon. Selected physical and chemical properties of the soils are listed in Table 1. The polygons and their attributes were connected with a uniform code. An extensive field survey was also per formed throughout Basrah Province using GPS receiver set into WGS84 at zone NUTM38 and later transferred to GIS and projected to the datum used for the satellite images (Jabbar et al., 2006). In the subsequent laboratory work, these soil samples were assayed and measured to get data of salinity and water content of soil. According to the soil salinity data, extents of soil salinization were graded as series of >5% (I), 2%–5% (II), 0.5%–2% (III), and <0.5% (IV), which denote high salinization, medium salinization, low salinization, and unaffected, respectively (Table 2) (U.S. Salinity Laboratory Staff, 1954).

Satellite data and processing of image

In this study, a Landsat 5 TM image of March 1990 and a Landsat 7 ETM+ image of March 2003 were used for detection of salinization risk and vegetation cover changes. The orbit data of the two images are 165/39, 166/38, 166/39, and 166/40 and their spatial resolution of 28.5 m; the pre-processing included geometric correction, where ground control points were chosen referencing to a topographic map of 1 : 250 000. In this research, a maximum likelihood classifier (MLC) was used to retrieve class boundary and two salinity indices were applied based on the concept of spectral response to salt-affected soils. All the thematic layers were generated in GIS environment at a scale of 1 : 250 000. The software's packages used for this study were (ERDAS version 9.1) and GIS (ArcGIS version 9.2). It is to note that spectral response in terms of digital number (DN) of salt-affected soils is relatively higher than other categories in Band 1 (B1) and Band 3 (B3). The following are two salinity indices, namely salinity index (SI): This index proposed by Tripathi et al. (1997) was applied, which gives relatively good results in the re-classification of salt-affected soils. The SI is calculated as

$$SI=(\text{Band } 1\times\text{Band } 3)^{1/2} \quad (1)$$

where Band 1 and Band 3 represent the spectral bands of the Landsat images.

Normalized differential salinity index (NDSI): This index is just the reverse of the NDVI for vegetation (Tripathi et al., 1997). The NDSI is basically the

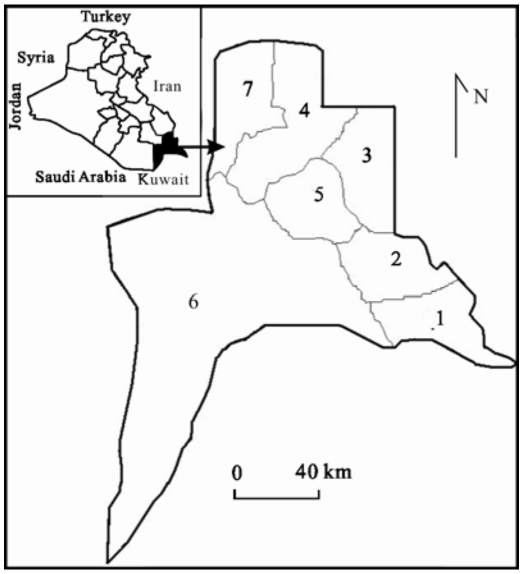

Figure 1. General location of study area in the southern part of Iraq. 1. Fao; 2. Abu Al-Khaseeb; 3. Shatt Al-Arab; 4. Al-Qurna; 5. Al-Basrah; 6. Al-Zubair; 7. Al Midaina.

Table 1 Some physical and chemical properties of soil type and their average value in study area

Physical and chemical	County name (ID)/area (km^2)						
	Khaseeb (2)/1 152	Midaina (7) /989	Qurna (4)/2 612	Zubair (6)/11 618	Basrah (5)/1 085	Fao (1)/98	Shatt Al-A. (3)/1 516
Sand ($g \cdot kg^{-1}$)	245.0	133.1	240.0	930.9	255.4	123.0	161.1
Silt ($g \cdot kg^{-1}$)	483.6	394.4	489.6	10.2	463.5	486.6	541.2
Clay ($g \cdot kg^{-1}$)	271.4	472.5	270.4	40.8	281.1	390.4	297.7
Texture	Silty L*	Silty clay	Silty L	Sandy	Silty L*	Silty clay	Silty L*
>0.50%*[1]	60.60	61.5	60.60	0.20	62.40	69.5	64.75
0.5%–0.25%*[1]	10.30	9.45	10.30	8.02	8.40	5.45	6.44
0.25%–0.10%*[1]	8.25	7.28	8.25	61.23	7.35	4.28	7.11
<0.10%*[1]	2.29	3.16	2.29	21.58	3.29	2.16	3.15
(mm)*[2]	0.18	0.17	0.20	0.28	0.22	0.21	0.19
Bulk D. ($g \cdot cm^{-3}$)	1.21	1.23	1.22	1.68	1.41	1.23	1.25
pH	7.87	7.95	7.82	7.84	7.85	8.90	7.80
O.M ($g \cdot kg^{-1}$)	3.70	3.10	3.75	0.19	2.60	3.20	3.73
EC dsm^{-1}	4.50	4.30	3.90	3.80	4.80	5.60	4.40
$CaCO_3$ ($g \cdot kg^{-1}$)	120.2	130.5	118.9	169.5	118.9	125.5	124.1
Ground water (m)	2–5	1–5	2–5	10–30	5–10	1–5	3–5

*. Loam; *[1]. aggregate size (mm); *[2]. grain mean diameter.

Table 2 Land surface features of pure pixels

Surface features	Average biomass (kg/30 m^2)	Average soil moisture (%)	Average soil salinity (%)	Salinity grades
Sand dune	0.09	0.1	0.05	IV
Sparse vegetation area	14.5	8.9	1.96	III
Luxuriant vegetation area	26.6	18.5	0.42	IV
Wet salty crust	1.3	21.9	9.18	I
Dry puffy salty crust	2.2	4.6	7.94	I
Salty meadow	4.9	5.8	3.67	II

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

$$NDSI=(Band\ 3-Band\ 4)/(Band\ 3+Band\ 4) \quad (2)$$

where Band 3 and Band 4 represent the spectral bands of the Landsat images.

Normalized difference vegetation index (NDVI): The most common form of vegetation index is the NDVI (Purevdorj et al., 1998). 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.

$$NDVI=(Band\ 4-Band\ 3)/(Band\ 4+Band\ 3) \quad (3)$$

where Band 3 and Band 4 are the red and near-infrared bands.

Soil salinity mapping

This part of the research aims to differentiate the salt-affected area from non-salt-affected areas using various methods of digital image classification and band match methods. To reach that objective, land use was classified using both unsupervised and supervised techniques applied to the Landsat TM and Landsat

ETM data coupled with ground truth investigation to verify the percentage of classification accuracy and to investigate the topographic and other related characteristics of the salt-affected area and those of non-salt-affected area. After getting the potential and/or salt-affected areas from image classification, different remote sensing indicators, such as the SI, the NDSI, and the NDVI, were employed to study how these indices work for salt-affected areas in the study area.

RESULTS AND DISCUSSIONS

Land Use/Cover Change Detection

Figure 2 shows the overall land use changes from 1990 to 2003. Results showed that, in 1990, vegetation land and sand land were the two largest land cover types, and they took up more than 48% of the total area. Urban area was ranked as the third size of the study area (17.3%), and unused land (salinized land) was ranked as the fifth (16.5%). However, from 1990 to 2003, the proportion of salinized land was ranked as the third in the total area. The contribution of vegetation land and water bodies was <40%. We can see that the areas of salinized land, sand land, and built-up land increased from 1990 to 2003. In contrast, the areas of vegetation land and water bodies decreased. The percentage of each land use/cover type from 1990 to 2003 is displayed in Fig. 2. As shown in this figure, salinized land, vegetation land, and sand land were the three largest land use types in the study area, except in 1990. For the main land use/cover types, results showed that the important change in Basrah Province was a decline in vegetation land and an increase in salinized land and sand land. In 1990, ~26.8% of the study area was covered by grassland and only 16.5% by salinized land. In 2003, vegetation land was reduced to 24.1%, whereas salinized land increased to 17.6% of the study area. However, unused land (salinized land) kept increasing and reached 20% of the total land area, nearly the same as proportion of cropland; in 2003, the most remarkable change was the increase of salinized land converted mainly from cropland and marshland.

The results of the transition matrix in Table 3 indicate the area increase or decline of each land use type. In the past decades, the salinized land increased by

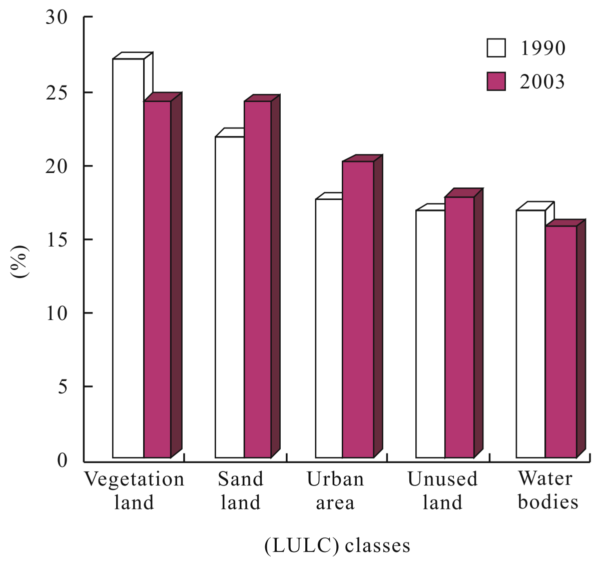

Figure 2. Land use/cover classes monitored from satellite image for the study area.

34.5%. Between 1990 and 2003, ~37.5% of vegetation cover and 45.9% of marshlands were transformed into salty meadow and wet salty crust, respectively. In addition, there were 16.6% of sand lands converted into dry puffy salty crust. According to the land use/cover conversion matrix table (Table 3), the areas that contributed the most to this change were vegetation land and water bodies. This may suggest logging and development. The majority of this change came from the development of vegetation land into an urban class. Marshes saw a decrease of 228.9 km^2 in size. Some of the marshes were converted to salinized land, whereas some were converted to urban and unused land. 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 1990s 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 the decrease in the flow of the Euphrates and Tigris Rivers from the upstream countries (UNEP, 2001). 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 this index (NDVI) has a significant correlation with water bodies' positive change (0.94). The declining vegetation is conspicuous in 2003 and larger than

Table 3 Land use/cover transition matrix (km^2)

	1990						
2003	Transition	Vegetation	Sand	Urban	Salinized land	Water	2003 totals
	Vegetation	3 107.2	769.1	318.8	270.2	130.5	4 595.9
	Sand land	972.2	2 869.2	349.6	258.5	108.1	4 557.7
	Urban area	489.2	116.1	2 302.5	567.3	319.4	3 794.9
	Salinized	440.4	266.3	221.1	1 814.4	213.9	3 356.3
	Water	101.6	98.3	107.1	236.2	2 412.6	2 955.9
	1990 totals	5 110.8	4 119.1	3 299.1	3 146.5	3 184.7	

that in 1990 in the study area. However, extended environment degradation was clearly found in the study location (Table 3). The results of the statistical analysis showed that saline area has a significant correlation with vegetation cover negative change (0.92).

Soil Salinity and Vegetation Indices Detection

The aim of this research was to identify how the different remote sensing indices: NDSI, SI, and the NDVI work for salt-affected soil delineation in this study location. Geologically, the soils in this area are alluvial deposits classified as silt loam, silt clay, and loamy sands (Table 1). Results from the indices analysis of the Landsat TM 1990 and Landsat ETM 2003 data showed that the indices that gave acceptable satisfactory results in distinguishing saline area from non-saline area were NDSI, SI, and NDVI. The post-processing results of NDSI and NDVI images by density slicing and band thresholding are shown in Figs. 3a, 3b, 4a and 4b. The result from the indices analysis of Landsat image data shows a significant increase of salt accumulation during the 13-year period, especially after 1990 when human activities increased salinization by excessive application of irrigation water without adequate drainage facilities (Jabbar, 2001). The results (Figs. 3a and 3b) and field survey show that nearly one-third of the area has potential soil salinity development. Moderately saline (2%–5%) and saline (>5%) soils occupy ~6 579.1 km^2 (34.5%) and low saline (0.5%–2%) cover ~12 490.8 km^2. Overall, it can be concluded that soils in the southern parts of Iraq, especially after beginning irrigation, show a significant salinity increase due to increase of groundwater level (range 1–30 m), particularly Fao and Abu Al-Khaseeb counties in the southeast part of the study area. The results were verified by comparing with topsoil conductivity values. Areas presently not affected by salinity but close to saline areas are potential areas for salinity development in the future, especially if they are also low-lying. In this respect, it is very important to take necessary measures in implementing proper land use plans and cultivation practices. Because salinity is a dynamic process, it is important to monitor the salinity process and to map its spatial distribution regularly. Although geostatistical technique is available to see the spatial structure, it takes lots of effort in collecting sufficient soil samples and their laboratory analysis. Therefore, the combination of geopedologic interpretation of the area and incorporation of band rotation seems to be useful in accessing salinity problem quickly.

The results (Figs. 4a and 4b) show that large-scale vegetation cover change had occurred in this area during the 13 years of this study. However, the vegetation area had decreased as the result of soil salinization. In fact, many canals and water reservoirs were found in the images in 1990 but not in 2003. Accordingly, this could be a possible reason for the decrease in area of cropland, although there are no data available to support this. Although there was declining vegetation found in study location, the results in Figs. 4a and 4b exhibited indications of vegetation change in cover. On the other hand, decreases in vegetation for study location areas were found, indicating the results of poor land management. This result revealed potentially high-risk environment degradation for further investigation. Results also suggested that enhancements to this method could help monitor the condition and extent of salinization cover areas on the margins of vegetation areas. The entire area was presumed to be subject to vegetation degradation mainly by anthropogenic

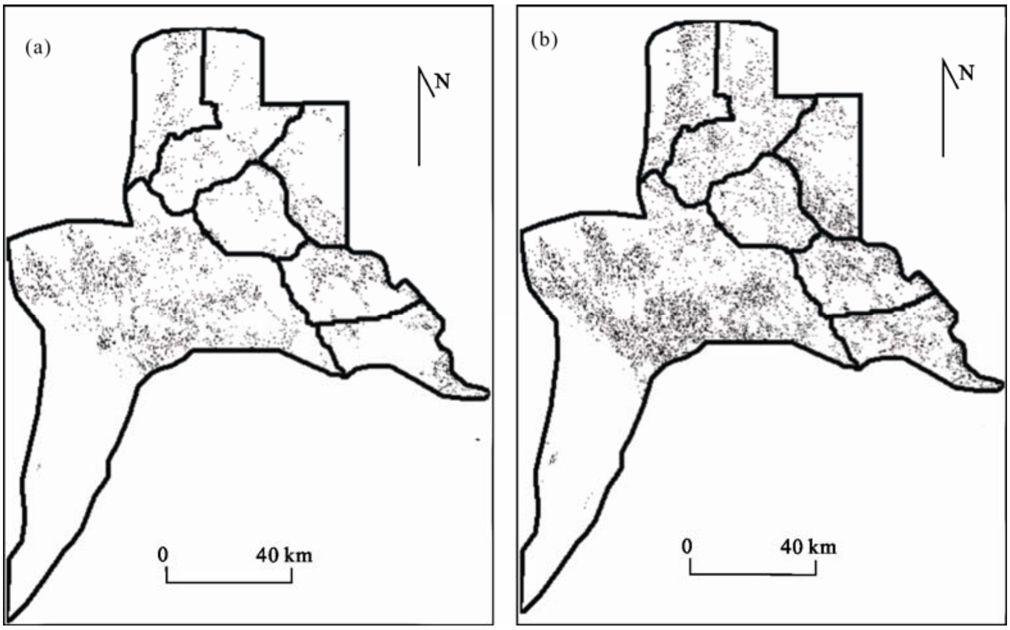

Figure 3. (a) Soil salinity distribution on the study area for the year 1990; (b) soil salinity distribution on the study area for the year 2003. Black dots represent salinization.

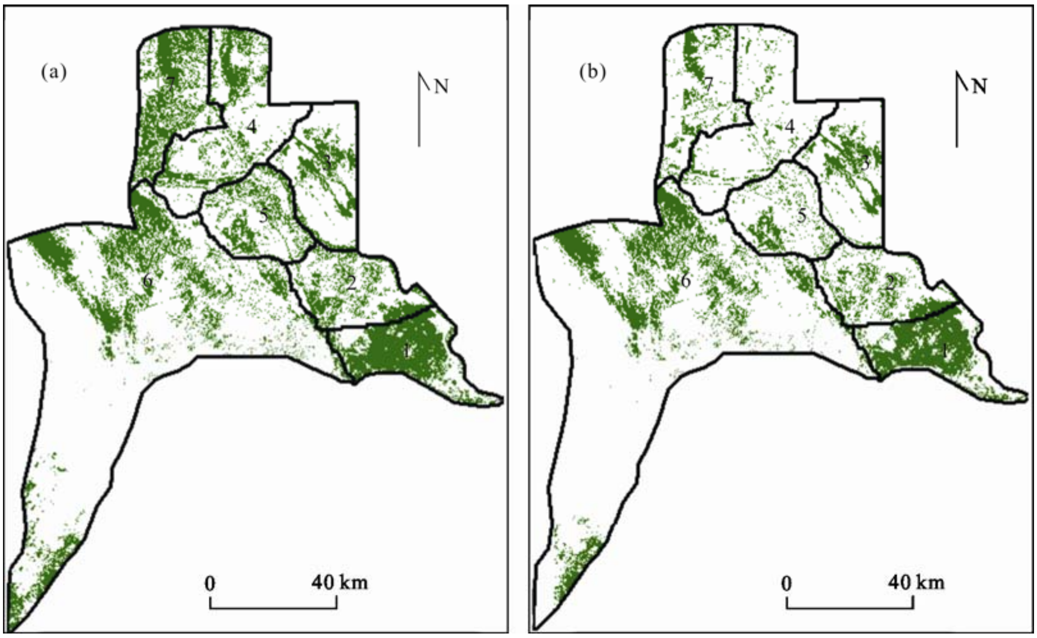

Figure 4. (a) Vegetation cover of Basrah Province in 1990 derived from NDVI; (b) vegetation cover of Basrah Province in 2003 derived from NDVI.

activities and climatic variation. Thus, 11.3% of the land area had vegetation cover in 2003, whereas 17.8% had vegetation cover in 1990, revealing the gravity of vegetation cover change problem in this study area.

Soil Salinity Status in the Study Area

The accumulation of salts in the surface and near-surface zones of soils is a major process of environment degradation and is also considered to be one of the main causes of low crop yields and loss of land and production. Soil salinity has long caused serious damage to arable land and grasslands in the middle and south parts of Iraq. Inadequate land reclamation and misuse of water resources have been the main reasons of secondary salinization. The environment degradation areas in 2003 are larger than those in 1990:

Abu Al-Khaseeb (2.40 km^2/a) and Fao (2.34 km^2/a) area is more than Al Midaina (0.64 km^2/a) and Basrah (0.86 km^2/a). 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. 5). The results of the statistical analysis showed that saline area has a significant correlation with vegetation cover negative change (0.92). The arid environment of the study area is characterized by low precipitation and high evapo-transpiration (Fig. 6). Human activities, however, increase salinization by excessive application of irrigation water without adequate drainage facilities. The soil in the transitional zone (soil-type clay loam and silty loam) is subjected to high to very high values; this is attributed to the existence of clay subsoil layer. According to information analysis, precipitation in the area has been reduced in the last two decades. Temperatures in other parts of the affected regions are increasing; consequently, the evaporation potential is accelerating and the formation of soil salinization is deteriorating by the above-mentioned trends. Agriculture expansion would be very risky in these surrounding areas because the soil salinization in this area reduces the vegetation cover. This results in shallow saline groundwater and accumulation of salt at the highest level due to the capillary movement of the water from extensive evaporation from the soil surface. The use of temporal soil data to determine salinity of agricultural lands has always been thought of as a fast and cost-effective method to monitor salt problems affecting crop yields. The use of remote sensing and GIS for monitoring salinity has been demonstrated to be feasible in large areas where salinity is already a serious problem. Overall, it can be concluded that soils in the southern parts of Iraq, especially after beginning irrigation, show a significant salinity increase due to rise of groundwater level (range 5–10 m), particularly in Abu Al-Khaseeb and Fao counties in the southeast part of the study area. To bring the salinity accumulation to an acceptable level, the excess water needs to be removed from the system by the selection of a proper drainage method and by applying water more efficiently using a proper irrigation method, and salinity level also needs to be monitored at certain intervals for sustainable agriculture in the area.

Evaluation of Environment Degradation by Soil Salinity

According to statistics of soil salinity thematic map, the total study area is 19 070 km^2. There into, the area of high salinization (grade I) is ~2 536.3 km^2 of total area, medium (grade II) is ~4 042.8 km^2, low (grade III) is 4 595.9 km^2, and unaffected area (grade IV) is ~7 894.9 km^2 (Table 4). In Table 4, we calculated the areas affected by various levels of salinity in Basrah Province. It is supposed that the whole area is subject to land degradation, as we mentioned previously, mainly by anthropogenic activities and climatic variation. The overall results were 41.4%, 24.1%, 21.2%, and 13.3% for none, slight, moderate, and high land degradation by soil salinity risk class, respectively. When salinity changes were compared as percentage between 1990 and 2003, Table 4 indicates very clear and significant results to show the increase of the percentage of saline soils and the decrease in non-saline soils. Whereas the non-saline soils were ~60% in 1990, the percentage decreased to ~41% in 2003. Levels of the saline soils from slight to strong also showed significant increase during these years. Especially, strongly saline soils increased from 1% to 7% and the increase was ~5% for slightly saline soils

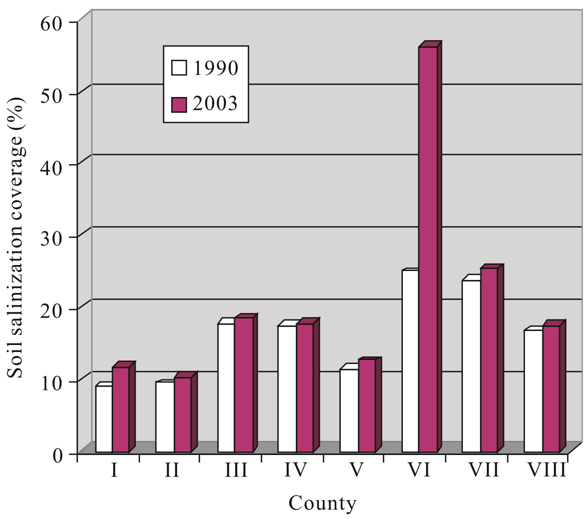

Figure 5. Soil salinization coverage percentages and their increasing rates in the study area during the period from 1990 to 2003. I. Abu Al-Khaseeb; II. Al Midaina; III. Al-Qurna; IV. Al-Zubair; V. Basrah; VI. Fao; VII. Shatt Al-Arab; VIII. total.

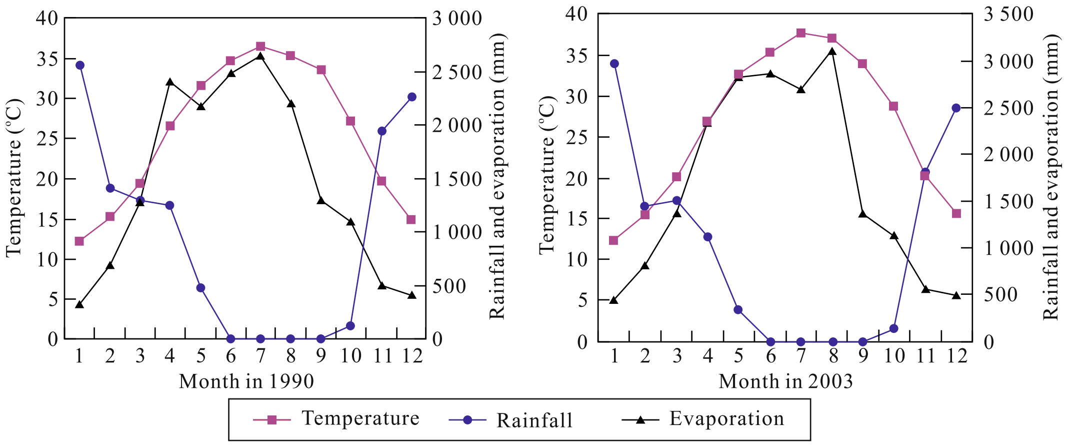

Figure 6. Monthly precipitation, potential evapo-transpiration, and temperature in Basrah Province for the years 1990 and 2003.

Table 4 Categories of land degradation by salinization and the proportion of each category

Class	Environment degradation by salinization	
	Area (km^2)	Proportion (%)
Unaffected environment degradation	7 894.9	41.4
Slight environment degradation	4 595.9	24.1
Moderate environment degradation	4 042.8	21.2
High environment degradation by	2 536.3	13.3
Total land area	19 070	100.0

in 13 years. Clearly, these results show the indication of environment degradation by salinization in Basrah Province. Soil salinity is a global environmental hazard and also a severe Iraqi environmental problem. It adversely affects crop yields and agricultural production in salt-affected farm lands. Salinity also affects water quality (rivers, streams, and lakes) and the structural integrity of buildings, roads, and other infrastructures. Furthermore, ecosystems such as wetlands and forests are being degraded by increasing salinity problems. In study location, more than 50% of land is adversely impacted by dryland salinity, which causes damage totally 20% each year. It was estimated that 6 579.1 km^2 of land in Basrah Province are at risk of soil salinity. As a result, agricultural production from farming industries such as grazing and cropping is diminished. Obviously, monitoring and managing salinity is one of the greatest natural resource management challenges in national, state, and regional levels.

Environment degradation by soil salinity areas increased rapidly in Basrah Province, and almost all take place on a lake or pond edge, river bank, or the flood plain, which were mainly intruded by the warming of climate, which in turn result in the amount of evapo-transpiration that exceeds 2 450 mm/a with average annual rainfall <100 mm (the drought and waterlog) increased also. In addition, the cultivation of original wetland is another main factor in the result of land salinization. On one side, plenty of wetland landscape suffered damage, and in some regions, the land salinization and desertification problem even turned serious, which destroyed the harmony between material cycle and energy flow among various ecosystems. On the other side, the habitat of wildlife is deteriorating and being lost, and the biological diversity is seriously being threatened. Especially, the decline of wetland by cultivation has made the function to store flood dropped gradually, causing the frequency of flood in downriver to increased greatly; aiming at the ecological frangibility character in the west of location for study, it is especially necessary to establish scientific and effective protection and recovery countermeasure. Establishing and modifying the policy and legal system, adjusting water from the north to south project, dredging the surface water system, promoting circulation between surface water and underground water, and setting up wetland resource monitoring system are also necessary in developing the restoration work of damaged wetland.

Causes of Expansion of Salinized Land

From the analysis for land use/cover change in

Basrah Province counties during the past 13 years, it can be found that the area of salinized land increased a lot, whereas farmland reduced rapidly. One direct reason for this increase of salinized land is the absence of drainage facilities; to a lesser extent, the irrigation practices used (flooding) are the major causes of these problems. Besides this reason, there are still two important ones for this great change.

Firstly, the dry climate, with evaporation being almost four times the annual rainfall, and high mineralization of underground water create circumstances suitable for salt accumulation as the soil salt capacity increases gradually.

Secondly, human activities exacerbated the salinization and produce secondary salinization. On one hand, the water conservancy project blocked the hydraulic link between the floodplain and the river, leading to higher level of groundwater, and destroyed the water-salt balance and induced salinization. On the other hand, the areas occupied by the marshlands have been affected the most, with the largest changes occurring in the 1990s 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 (UNEP, 2001).

What's more, these changes bore an interactive relationship with the environment degradation, especially increased air temperature and variable precipitation. Climate warming created a potential environment for soil salinization. Apart from natural factors, land use policy, economic systems, and population growth were also main driving forces that jointly determined how local dwellers changed the landscape pattern. The results drawn from our study are important for scientists as well as policymakers for assessing a number of cutting-edge issues associated with global change and sustainability.

CONCLUSIONS

Environmental degradation is a complex process. In this research, we apply a NDSI and SI for detecting the salinization change of soil surface to monitor the environmental degradation process. Soil salinization indices show that most salinity problems were located along drainage canals. The salinization situation is quite alarming when comparing the change of salinization indices over a 13-year period. Evidence is that the existing drainage system, along with the use of groundwater for irrigation, reduces the extent of soil salinization. However, the reuse of poor quality water to supplement irrigation supplies by the downstream farmers and the failure of a few drainage sumps are likely to disturb the water balance resulting in an increased risk of salinity in the area. The vegetation growth analyzed through NDVI tends to be lower along drainage and higher along the irrigation canals due to the inequity water distribution and locational disadvantage of the drains and vice versa. High NDVI values for almost all over the study area with demand-oriented water supply thus give the solution to resolve the remaining salinity problem. Lastly, it is concluded that the water shortage is one of the fundamental problems in the area to reclaim the soil for sustainable productive soils.

ACKNOWLEDGMENTS

This study was supported by the Basrah University, Iraq and the Outstanding Doctorate Thesis Foundation of Huazhong University of Science and Technology, the Youth Chenguang Project of Science and Technology of Wuhan City of China (Nos. 20015005037 and 20055003059-34), and the Natural Science Foundation of Hubei Province (No. 2005ABA047).

REFERENCES CITED

Awasthi, K. D., Sitaula, B. K., Singh, B. R., et al., 2002. Land-Use Change in two Nepalese Watersheds: GIS and Geomorphometric Analysis. *Land Degradation & Development*, 13(6): 495–513, doi:10.1002/ldr.538

Cayuela, E., Estan, M. T., Parra, M., et al., 2001. NaCl Pre-Treatment at the Seedling Stage Enhances Fruit Yield of Tomato Plants Irrigated with Salt Water. *Plant and Soil*, 230(2): 231–238

Collado, A. D., Chuvieco, E., Camarasa, A., 2002. Satellite Remote Sensing Analysis to Monitor Desertification Processes in the Crop-Rangeland Boundary of Argentina. *Journal of Arid Environments*, 52(1): 121–133

Dehaan, R., Taylor, G. R., 2003. Image-Derived Spectral Endmembers as Indicators of Salinization. *International Journal of Remote Sensing*, 24(4): 775–794

De Jong, S. M., 1994. Derivation of Vegetative Variables from a Landsat TM Image for Modeling Soil-Erosion. *Earth Surface Processes and Landforms*, 19(2): 165–178, doi:10.1002/esp.3290190207

Dymond, J. R., Begue, A., Loseen, D., 2001. Monitoring Land at Regional and National Scales and the Role of Remote Sensing. *International Journal of Applied Earth Observation and Geoinformation*, 3(2): 162–175

Farifteh, J., Farshad, A., George, R. J., 2006. Assessing Salt Affected Soils Using Remote Sensing, Solute Modeling, and Geophysics. *Geoderma*, 130(3–4): 191–206

Goetz, A. F. H., Herring, M., 1989. The High Resolution Imaging Spectrometer (HIRIS) for EOS. *IEEE Transactions on Geoscience and Remote Sensing*, 27(2): 136–144

Goetz, A. F., Vane, G., Soloman, J. E., et al., 1985. Imaging Spectrometry for Earth Remote Sensing. *Science*, 228(4704): 1147–1153

Hick, P. T., Russell, W. G. R., 1990. Some Spectral Considerations for Remote Sensing of Soil Salinity. *Australian Journal of Soil Research*, 28(3): 417–431, doi:10.1071/SR9900417

Jabbar, M. T., Chen, X. L., 2006. Land Degradation Assessment with the Aid of Geo-Information Techniques. *Journal of Earth Processes and Landforms*, 31(6): 777–784, doi:10.1002/esp.1298

Jabbar, M. T., Shi, Z. H., Wang, T. W., et al., 2006. Vegetation Change Prediction with Geo-Information Techniques in the Three Gorges Area of China. *Pedosphere*, 16(4): 457–467

Jabbar, M. T., Al Bassam, B. F., Hu, G. D., 2004. Application of Remote Sensing and GIS in Study of Aeolian Deposits Distribution and Sand Dune Movements in Northern Part of Shaanxi Province, China. *Journal of China University of Geosciences*, 15 (Suppl.): 85–91

Jabbar, M. T., 2003. Using Remote Sensing and GIS Techniques to Study Soil Degradation Processes in North Shaanxi Province, China. *Journal of China University of Geosciences*, 14(4): 356–362

Jabbar, M. T., Hu, G. D., Chen, J. G., 2002. Study of Sand Dunes and Their Effect on Desertification of Cultivated Lands in Shaanxi Province, China—Using Remote Sensing Techniques. *Journal of China University of Geosciences*, 13(3): 234–239

Jabbar, M. T., 2001. Soil Loss by Wind Erosion for Three Different Textured Soils Treated with Polyacrylamide and Crude Oil, Iraq. *Journal of China University of Geosciences*, 12(2): 113–116

Jia, B. Q., Zhang, Z. Q., Ci, L. J., et al., 2004. Oasis Land-Use Dynamics and Its Influence on the Oasis Environment in Xinjiang, China. *Journal of Arid Environments*, 56(1): 11–26

Lambin, E. F., Turner, B. L., Helmut, J. G., et al., 2001. The Causes of Land-Use and Land-Cover Change: Moving beyond the Myths. *Global Environmental Change*, 11(3): 261–269

Lichtenberg, E., Ding, C., 2008. Assessing Farmland Protection Policy in China. *Land Use Policy*, 25(1): 59–68

Metternicht, G. I., Zinck, J. A., 2003. Remote Sensing of Soil Salinity: Potentials and Constrains. *Remote Sensing of Environment*, 85(1): 1–20

Mougenot, B., Pouget, M., Epema, G. F., 1993. Remote Sensing of Salt Affected Soils. *Remote Sensing Reviews*, 7(3–4): 241–259

Purevdorj, T. S., Tatelshi, R., Ishiyama, T., et al., 1998. Relationships between Percent Vegetation Cover and Vegetation Indices. *International Journal of Remote Sensing*, 19(18): 3519−3535

Shen, R. P., Kheoruenromne, I., 2003. Monitoring Land Use Dynamics in Chanthaburi Province of Thailand Using Digital Remotely Sensing Images. *Pedosphere*, 13(2): 157–164

Tripathi, N. K., Rai, B. K., Dwivedi, P., 1997. Spatial Modeling of Soil Alkalinity in GIS Environment Using IRS Data.18th Asian Conference on Remote Sensing, Kualalampur. 81–86

U.S. Salinity Laboratory Staff, 1954. Diagnosis and Improvement of Saline and Alkali Soils. In: Richards, L. A., ed., USDA Handbook. U.S. Gov. Print. Office, Washington. 60: 7–33

UNEP, 2001. The Mesopotamian Marshlands: The Demise of an Ecosystem. Early Warning and Technical Assessment Report, UNEP/DEWA/TR.01–3. http://www.grid.unep.ch/activities/sustainable/tigris/mesopotamia.pdf (accessed May 2003)

Verbeiren, S., Eerens, H., Piccard, I., et al., 2008. Orshoven, Sub-Pixel Classification of SPOT-VEGETATION Time Series for the Assessment of Regional Crop Areas in Belgium. *International Journal of Applied Earth Observation and Geoinformation*, 10(4): 486–497

Verma, K. S., Saxena, R. K., Barthwal, A. K., et al., 1994. Remote Sensing Technique for Mapping Salt Affected Soils. *International Journal of Remote Sensing*, 15(9): 1901–1914, doi:10.1080/01431169408954215

Vitousek, P. M., Mooney, H. A., Lubchenco, J., et al., 1997. Human Domination of Earth's Ecosystems. *Science*, 277(5325): 494–499