USING LANDSAT THEMATIC MAPPER DATA TO DETECT AND MAP VEGETATION CHANGES IN KUWAIT

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ABSTRACT

Remotely sensed satellite images are invaluable data sets for land-cover analysis on either local, regional or global scales. Equally important is to employ digital enhancement techniques sensitive to minor vegetation changes, especially in areas with low vegetation cover. In this study, Landsat Thematic Mapper (TM) digital image data acquired on February 4, 1987, and February 28, 1993, respectively, were geometrically and radiometrically calibrated and used to detect and map vegetation changes in the desert environment of southern Kuwait. The normalized difference vegetation index (NDVI), an index related to photosynthetically active green biomass, was used as input to a selective principal component analysis procedure. The change image or the second principal component (PC2) mapped 19.82% of total information related to vegetation between the two dates. The increase in vegetation between the 1993 and 1987 images was supported by recorded rainfall data that increased by about three times for the same time of the year for the two dates. Vegetation increase was observed mainly within the Kuwait City limits and cultivated farms where plants are irrigated. The majority of the desert areas with active and smooth sand sheets displayed insignificant or no vegetation changes between the two dates.

1. INTRODUCTION

Mapping of land-cover from space offers an unequaled and inexpensive technique to monitor vegetation changes on local, regional and global scales. The principal image sensor for global or broadscale land-cover analysis has been the Advanced Very High Resolution Radiometer (AVHRR) onboard National Oceanic and Atmospheric Administration (NOAA) series of polar orbiting meteorological satellites. Several studies using NOAA AVHRR data to monitor vegetation cover in diverse environments have been reported in the literature (Townshend and Justice, 1986; Choudhury and Tucker, 1987; Goward et al., 1991; Justice et al., 1991). The popularity of AVHRR is due to the availability and the relatively inexpensive data sets. However, a major disadvantage is the large pixel resolution of 1.1 km per pixel. For regional and detailed local studies, Landsat Thematic Mapper (TM) and Satellite Pour d'Observation de la Terré (SPOT), with spatial resolutions of 30 m and 10-20 m, respectively, have provided invaluable information related to land-cover analysis (Dymond et al., 1992; Lauver and Whistler, 1993; Schriever and Congalton, 1995).

Desertification in an arid environment, such as Kuwait, entails land degradation, whereby desert scrubs are gradually replaced by sand and/or bare soil. The process could be natural/climatic induced or anthropogenic. The use of remote sensing and other methods to map seasonal and yearly vegetational changes are critical to studying desert dynamics and could help in the recommendation of the best techniques to combat desertification. Such techniques facilitate the demarcation of desert boundaries and areas threatened by desertification, mapping of arable lands, as well as areas susceptible to erosion and generation of sand and dust storms. Vegetation, undoubtedly, is the single most effective and environment-friendly way to combat desertification, stabilize soils and reduce wind erosion in arid environments. In arid an environment with low vegetation cover, it is imperative to use sophisticated digital enhancement techniques so that satellite images can map minute seasonal and inter-annual vegetation variations. A method that is sensitive to slight vegetation changes would be very important and serve as an early warning for areas under threat from desertification. Remote sensing analysis of land-cover will continue to provide more useful information, especially with the launching of satellites with higher spatial resolution of 1-3 m by 1997 (Fritz, 1996).

Described herein is a study that utilized multitemporal Landsat TM bands to detect and map vegetation changes in the arid environment of Kuwait. The study area was extracted from Landsat TM digital image data of path 165, row 40, that were acquired on February 4, 1987, and February 28, 1993, respectively. The images were selected to include the principal types of vegetation, namely, undershrubs, perennial shrubs and spring ephemerals. The normalized difference vegetation index (NDVI) images were used as an input into an automatic change detection procedure that mapped vegetation differences between the two dates.

The study was conducted in the southeastern part of the State of Kuwait, extending south of Kuwait City to the Kuwait-Saudi Arabian border. Like most parts of the Arabian Shield, Kuwait is characterized by a desert type of environment with scanty rainfall, and a dry, hot climate. Summer is very hot, especially July and August, with a mean temperature of 37.4°C and maximum mean temperature of 45°C. The average total precipitation is approximately 100 mm/y and the rate of evaporation is 16.6 mm/d. The winds in the area are from the northwest and, to a lesser extent, from the southeast, and have a pronounced influence on the oceanographic and sedimentological processes. Dust and dust storms, locally known at 'toze', occur in the Kuwait region throughout the year but are more frequent during the spring and summer months, i.e., March to August. Kuwait is a low-relief desert country with a maximum relief of approximately 125 m. The land surface slopes gradually northeastwards with an average gradient of approximately 2 m/km. Kuwait's desert can be divided into four main provinces, namely: (1) Al-Dibdibba gravely plain; (2) southern desert flat; (3) coastal flat; and (4) coastal hills (Khalaf et al., 1984). The surface is overlain by several recent sediment deposits that include, eolian, residual, playa, desert plain, slope, and coastal deposits (Figure 1). Eolian deposits are the most predominant and account for 50% of the surface deposits. Observed surface outcrops consist of clastic deposits which are locally called the Kuwaiti Group, and range in age from Miocene to recent.

2. METHODOLOGY

The Landsat TM digital images were geometrically registered and radiometrically calibrated to each other to facilitate their comparison. The NDVI images for the two dates were used as input to an automatic change detection procedure using selective principal component analysis. Landsat TM band 3 images were further enhanced to improve the overall information content in the low frequency end of the images. Image processing was performed on a UNIX-based SUN workstation with PCI's EASI/PACE image processing software at Kuwait Institute for Scientific Research's (KISR) Remote Sensing Laboratory.

Radiometric calibration of satellite imagery is critical in multitemporal and change detection studies due to the degradation by haze. Haze, caused by scattering of electromagnetic waves, increases the overall radiance of an image thereby reducing the image contrast as well as degrading the spatial resolution of the sensor. The haze effect is much more severe on the shorter than the longer wavelength. The true reflectance, which is characteristic of a target, is modified by the atmosphere through, (1) atmospheric scattering; (2) attenuation, i.e., absorbing of the energy reflected by the Earth; and (3) ground scattering. For quantitative analysis or comparison of multitemporal images, it is imperative that the gray level reflect the true spectral reflectance of the target area, i.e., the elimination of the atmospheric influence.

The atmospheric correction program, ATCOR (Richter, 1991), that is part of PCI software package was used to derive the true spectral image of the TM bands used in this study. The program employs the LOWTRAN-7 atmospheric model code and adjusts each pixel to account for atmospheric influences such as albedo, optical depth and aerosol concentrations. The program incorporates a catalogue of atmospheric functions to calculate ground reflectance values for cloud-free images. The catalog compiled for Landsat multispectral scanner (MSS), TM, and SPOT consists of aerosol types and concentration, zenith angles, sensor view angles, and ground altitudes for different standard atmospheres. The program specifically employs the following three steps;

- ATCOR0 .... Determines ground visibility.
- ATCOR1 .... Calculates reflectance image with no adjacency effect.
- ATCOR2 .... Calculates reflectance image with adjacency effect.

Several change detection technique applications to satellite digital data have been reported in the literature. Some of these include image difference, ratioing, principal component analysis, and selective principal component analysis (Jensen and Toll, 1982; Singh, 1989; Chavez and Kwarteng, 1989; Chavez and MacKinnon, 1994). The applied radiometric correction can either be absolute or relative depending upon the intended use. In absolute calibration, the satellite digital number (DN) is converted to ground reflectance, whereas in the relative sense, the same DN in two images represent the same reflectance. A third type of calibration is a hybrid between the absolute and the relative methods. Application of relative calibration is only meaningful if the DN changes between two images is statistically small and do not alter the overall dynamic range of the images. Such conditions are usually observed in arid and semi-arid environments (Chavez and MacKinnon, 1994).

In this study, we applied selective principal component in the same manner as used by Chavez and Kwarteng (1989), where only two bands from the same image are used as input to principal component analysis (PCA). Principal component analysis is a statistical technique that rotates the axes of a multi-dimensional image space in the direction of maximum variance. The generated components or axes, that are simple linear combinations of the original image data, are orthogonal to each other and, thus, have no further mathematical relations. Eigenvectors are used as multiplication coefficients or loadings in the PCA for each pair of input bands. By being selective and using two images or bands as input to PCA, information that is common to the two images/bands, typically topographic, albedo or reflectance, is mapped to the first component (PC1), whereas information that is unique to either of the input images is mapped to the second component (PC2) (Chavez and Kwarteng, 1989). Consequently, PC2 maps the spectral contrast of two bands from the same image, or the temporal contrast when the images were taken at different times. In transforming the data into a new coordinate system, the selective principal component technique performs a first-order relative image to image calibration and, therefore, automatically eliminates most low-frequency noise between the two images, which invariably includes atmospheric and solar effects. Such noise reduction capabilities enhance the quality of images generated. A major advantage of selective principal components over the traditional PCA analysis, with several bands or images as input into PCA, is that the analysis and interpretation of the results are relatively easy and straight-forward (Chavez and Kwarteng, 1989).

3. DISCUSSION OF RESULTS

Optical satellite images of desert environments can often be dull with little contrast because of the overshadowing of the high frequency information in the dominant low frequency

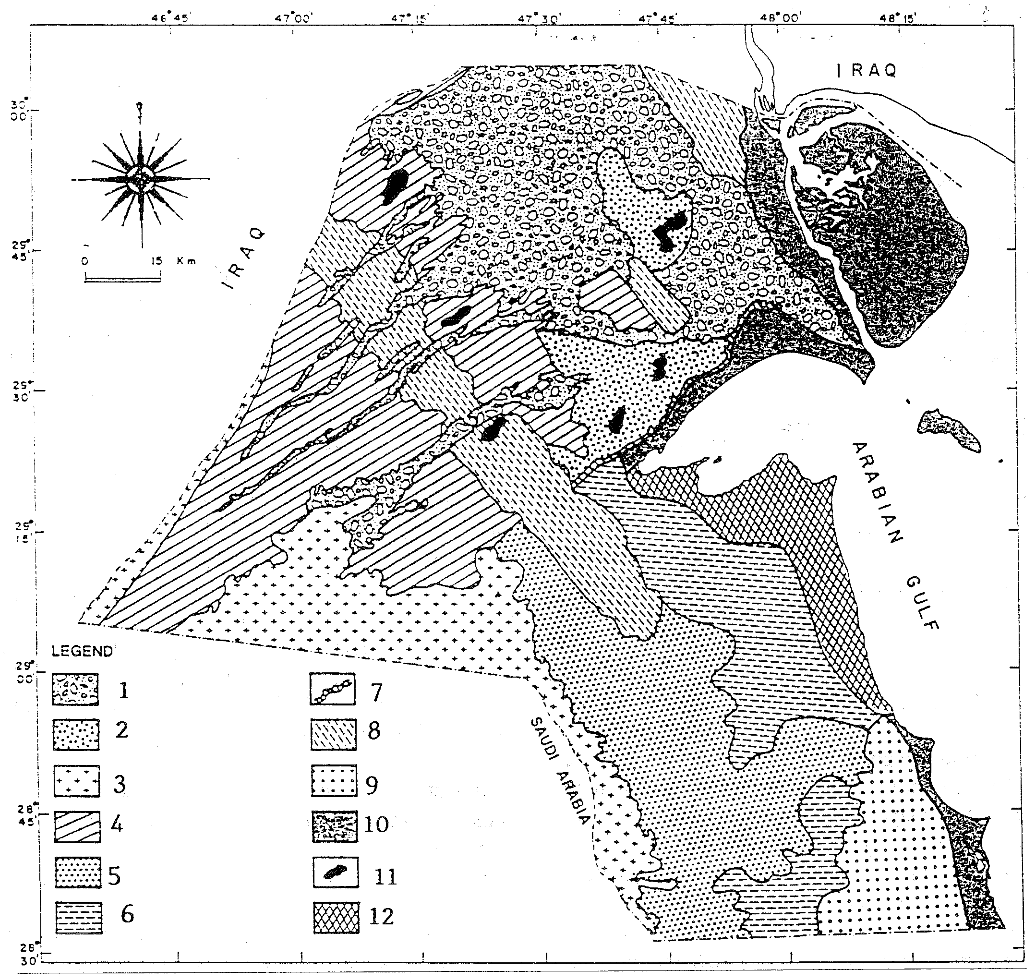

Figure 1. Surface sediment map of Kuwait (1990). 1 = Gravel lag, 2 = Desert floor deposits covered by siliclastic granule lag, 3 = Desert floor deposits covered by pebbly and granule lag rich in calcretic debris, 4 = Deflated rugged sand sheets, 5 = Active sand sheets, 6 = Smooth sand sheets, 7 = Fall dunes, 8 = Barchan dunes, 9 = Barchanoid ridges, 10 = Coastal plain deposits, 11 = Playa deposits, 12 = Urban areas (Khalaf and Al-Ajmi, 1993).

Table 1. Statistics of the Principal Component Analysis of the 1987 and 1993 TM NDVI images.

Input Channels	Mean Channels	SD Channels	PC1 Loadings	PC2 Loadings	PC1 % Variance	PC2 % Variance
NDV1-87	167.05	3.84	-0.387	-0.922	80.18	19.82
NDV1-93	168.48	6.03	-0.922	0.387		

bright and dark frequency areas (Kwarteng and Chavez, in press). To maximize the spatial information in the TM data used in this study, a high pass filter with a relatively large kernel size of 201 by 201 pixels and a 50% addback option was used to enhance the high frequency information in both the bright desert and other relatively dark areas. The filtered results were edged enhanced with a 7 by 7 filter to sharpen the local/textural information or very high frequency features (Kwarteng and Chavez, in press). The vast improvement over the non-processed image is more spectacular when printed on a large scale, and also in color composites, such as TM bands 2, 4, and 7. However, due to publication restrictions, only black and white images are shown in this paper. Additionally, image interpretation was originally done on a scale of 1:100,000, but reduced considerably for publication. The enhanced TM band 3 image acquired on February 28, 1993, is shown in Figure 2. The Arabian Gulf, shown as the black, was masked and excluded from further processing. The north-south-trending dark area in the middle of the image is the scar from the burned oil wells and the subsequent cleanup activities at the Greater Burgan oil field. The Greater Burgan, consisting of Burgan, Magwa, and Ahmadi oil fields, is the second largest oil field in the world. During the 1991 Gulf War, the Iraqi forces detonated several pounds of explosives laid against all the active 810 oil wells in Kuwait. In the ensuing environmental disaster unequaled in the world's history, 656 oil wells were set ablaze while 74 others gushed uncontrollably from the damaged well heads (Petroleum Economist, 1992). During the peak of the fires, 365 burning wells were observed at the Greater Burgan oil field (Kwarteng and Bader, 1993).

The most commonly used technique for vegetation analysis is the NDVI, a parameter derived from the red and near-infrared channels. The ratio is computed from TM bands as follows:

$$NDVI = (TM4-TM3)/(TM4 + TM3) \qquad (1)$$

where TM3 and TM4 are DN values in the red (0.63-0.69 μm) and near-infrared (1.55-1.75 μm) bands, respectively. The ratio is a measure of the deviations between a vegetation spectrum's chlorophyll absorption minimum and the infrared plateau and, thus, a direct indication of the amount of photosynthetically active green biomass (Tucker and Sellers, 1986). The NDVI image computed for the two dates are presented in Figures 3 and 4. The images were linearly stretched to occupy the dynamic range 0-255. A histogram matching procedure from PCI software was used to create a lookup table matching the NDVI image of February 4, 1987, to that of February 28, 1993. Consequently, the same DN values in both Figures 3 and 4 represent the same reflectance values. The gray color denotes areas with insignificant vegetation or NDVI values. The darker than gray areas which include standing water, coastal sabkhas, soot from oil fires, and man-made structures (i.e., tar roads, airport runways and buildings), have no relations with NDVI. In Figure 3, such areas are observed mainly within the Kuwait City limits, north and southeast of Kuwait International Airport. The dark tones along the coast south of Ras Al-Qulaiah represent sabkhas. The black spot at the Wafra oil field represent an oil spill that occurred before February 1987. For the 1993 image, such areas include the oil lakes, soot, and tarmats found at the Burgan oil field and, to a lesser extent, at the Wafra oil field. Winds in the area are predominantly from the northwest and, to a lesser extent, from the southeast. Therefore, most of the soot is observed southeast of the Burgan oil field. The amount of vegetation that normally would have been found in the oil fields and areas downwind had been reduced drastically due to the negative effect of the burning of the oil wells. A comparison of Figures 3 and 4 show that vegetation within the coastal wetlands east of Wafra farms had been adversely affected by the burning oil wells.

The lighter than gray tones represent the distribution of vegetation or photosynthetically active areas that include both natural vegetation and cultivated crops. The degree of whiteness is a measure of the vegetation vigor. The extreme white areas represent cultivated farms. In both images, vegetation is observed mostly to the north and east of the Burgan oil field, within the Kuwait City limits and at the Wafra farms. The suburb of Ahmadi with several trees show up as white on both images. The 1987 image (Figure 3) shows that the majority of the desert lands had less vegetation compared with the February 1993 image that exhibits increase in greenness/biomass in both the desert and city areas. Variation in vegetation distribution between the two images was primarily due to climate and, more importantly, rainfall. Rainfall in Kuwait is scanty, erratic, and fluctuates from year to year with the main rainfall season occurring between November to April. The total precipitation recorded at the Kuwait International Airport Observatory from November 1986 to February 1987 was 44.9 mm. For the same period between November 1992 to February 1993, the amount of rain recorded was 150.2 mm. Lack of rainfall intensifies aridity and causes degradation of natural vegetation. For most regions, shifting sand dunes and sand sheets are incapable of sustaining plant life. Kuwait's vegetation consists of undershrubs, perennial herbs and spring ephemerals. The vegetation types are controlled by four major ecosystems, i.e., sand dunes, desert plain, desert plateau, and salt marsh and saline depressions (Halwagy and Halwagy, 1974). The major plant communities are: (a) *Cyperus conglomeratus*; (b) *Rhanterium epapposum*; and (c) *Hammada salicornica,* with the first two being the most predominant in the study area. Comparison of both images show that the Wafra farms were extended further to the east from 1987 to 1993. Furthermore, the 1993 image shows higher plant vigor/biomass and most likely yielded abundant crops compared with 1987.

The NDVI images of the two dates were used as input to the selective PCA technique. The resulting image statistical variance (Table 1) is related to the surface spectral responses such as vegetation and soil. PC1, which represents albedo, accounts for 80.18% of the total scene variance (excluding the Arabian Gulf) and is composed of negative weighting for the input bands. PC2 that maps vegetation related differences between the two dates is 19.82% of the scene variance (Table 1). The ordering of the PCA (i.e., PC1 and PC2) is influenced by both the image statistics and spatial abundance of surface materials. Because the spectral property mapped into each NDVI image are related to biomass/greenness, any changes between the image statistics is associated with temporal vegetation variations. From Table 1, this can be interpreted as an increase in vegetation of 19.82% from 1987 to 1993 and, conversely, a 19.82% decrease in biomass from 1993 to 1987. The weighting mapped into PC1 and PC2 is influenced by the magnitude of the standard deviation (SD) and statistical dimensionality of the images that are related to sensor gain, offsets, and spectral differences (Loughlin, 1991). Even

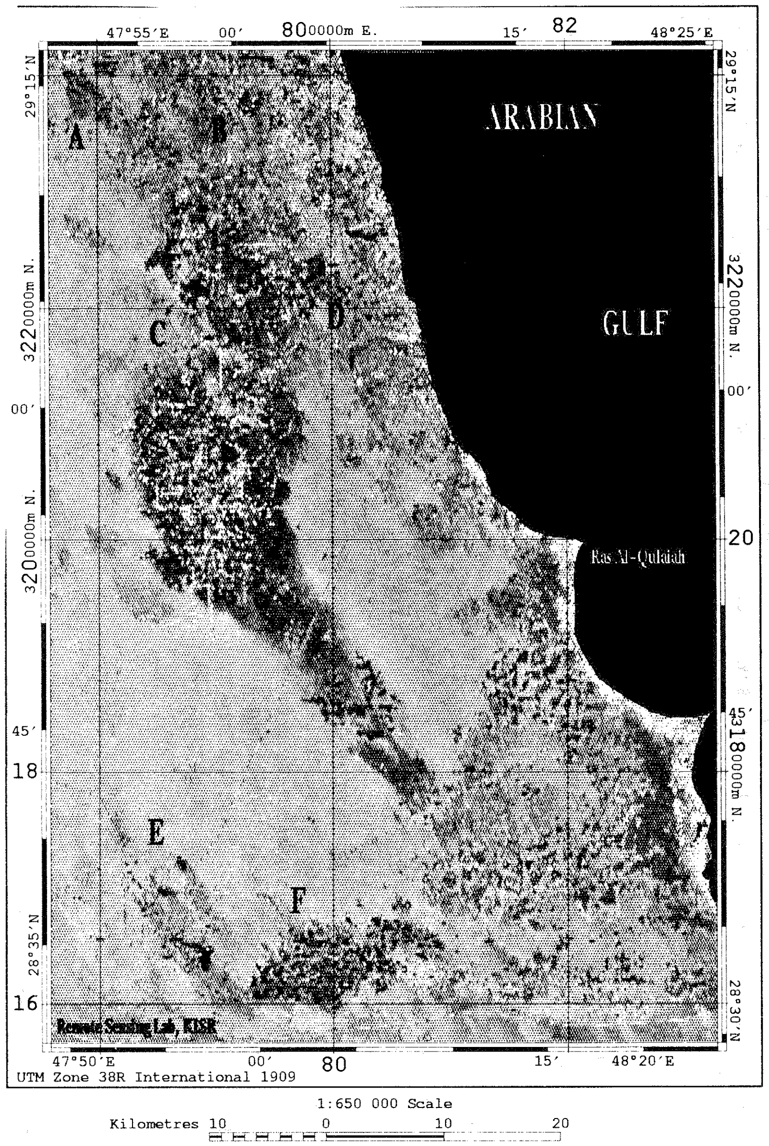

Figure 2. Enhanced Landsat TM band 3 image of the study area. The image was acquired on February 28, 1993. Annotation in the image refers to the following locations:
A = Experimental farm, B = Kuwait International Airport, C = Greater Burgan oil field, D= Suburb of Ahmadi. E = Wafra oil field, and F = Wafra farms.

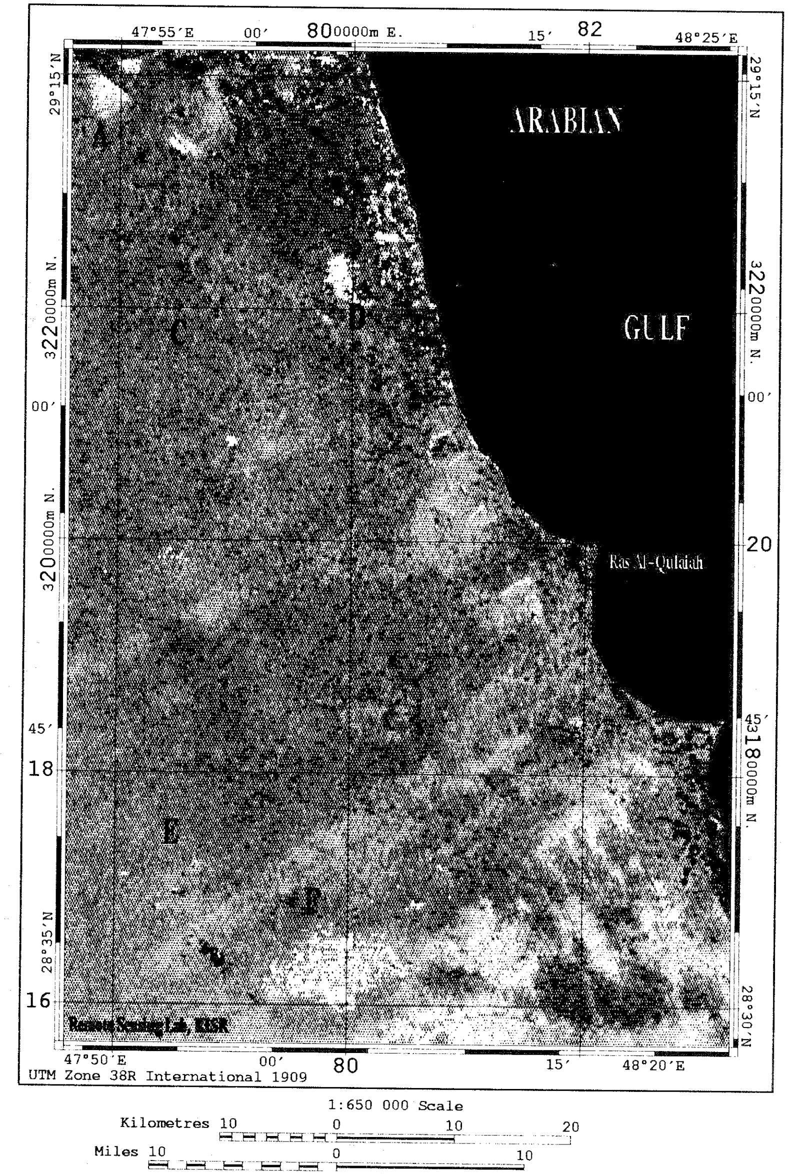

Figure 3. NDVI image of February 4, 1987, TM digital data. Refer to Figure 2 for the annotation.

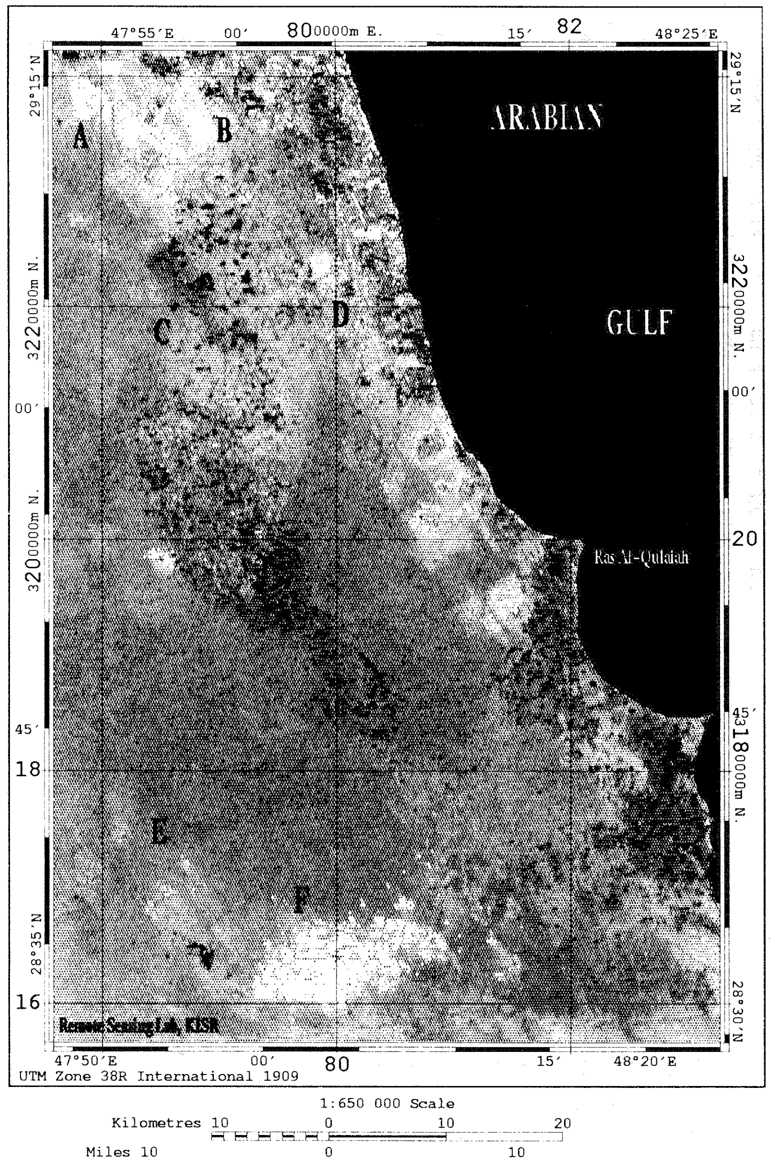

Figure 4. NDVI image of February 28, 1993, TM digital data. Refer to Figure 2 for the annotation.

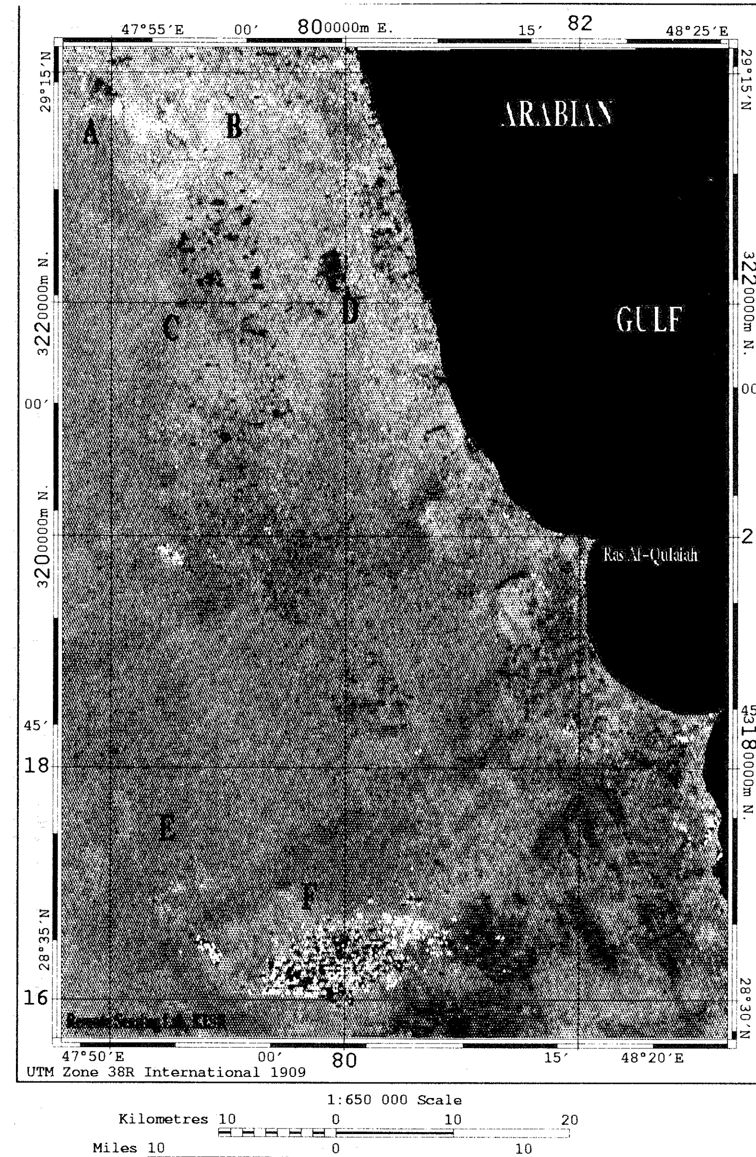

Fig. 5. PC2 image of the NDVI images of February 4, 1987, and February 28, 1993. Refer to figure 2 for the annotation.

though the means of the two images are about the same, the large SD of the 1993 image is responsible for its dominance in the PC1 image (Table 1).

In the PC2 image for the two data sets, gray tones indicate insignificant or no NDVI changes (Figure 5). Such areas are observed mostly in the desert with shifting sands and barren soil that are incapable of supporting vegetation. The negative loading of the 1987 NDVI image translates to dark pixels and the positive loading of the 1993 NDVI image bright pixels. Thus, white areas denote increase in vegetation from 1987 to 1993 and dark areas decrease in vegetation from 1987 1993. The prominent areas with increase in vegetation are observed in the north and east of Burgan oil field. However, there a few locations that show increase or decrease in NDVI values that are not related to vegetation. An example is the oil spill at Wafra oil field that appears as white on the PC2 image. The oil spill was present in February 1987, but was increased during the 1991 Gulf War and hence the white color. The oil spill shows up as black in both Figures 3 and 4 indicating no relations with vegetation. Also, some of the coastal sabkhas show up as white due to the increase in their water content from 1987 to 1993. The noticeable black/dark areas with decrease in vegetation from 1987 to 1993 are the oil lakes at Burgan oil field, the town of Ahmadi, sections of the experimental and Wafra farms, and some coastal sabkhas. The dark sections of the Wafra farms denote decreased plant vigor or non-cultivated areas from 1987 to 1993.

4. CONCLUSION

The ability to detect and monitor vegetation changes is crucial to detecting anomalous conditions that could enhance desertification or disrupt the plant ecosystem in arid environments. The technique offered by satellite remote sensing in global, regional and local vegetation analysis is second to none as minor changes can easily be detected. Desertification in an arid environment is a natural process that cannot be completely eliminated, but the ability to spot trend could be useful in early warning or remedial solutions.

Analysis of Landsat TM images showed sensitivity to detecting vegetation changes in the arid environment of Kuwait. The TM NDVI images proved effective in mapping vegetation changes that occurred between the data sets acquired on February 4, 1987, and February 28, 1993. The NDVI images were used as input to a selective PCA procedure. Because the major spectral information mapped by the NDVI image is related to active green biomass, the change image (PC2) accounting for 19.82% of the total information between the two data sets represented vegetation increase between 1987 and 1993, and conversely a decrease of 19.82% comparing the 1993 and 1987 data sets. The observed vegetation variation was supported by rainfall data that increased by approximately three times between the two dates. Rainfall and irrigation as expected were therefore, the principal causes of vegetation variation in the study area. In the absence of abundant rainfall and irrigation the desert environment can only support a few desert plants. By virtue of the adverse effect of the burning of the oil lakes that occurred during the 1991 Gulf War, there was loss of vegetation in 1993 compared with what would have been observed with the high rainfall.

Some authors have reported the ineffectiveness of the NDVI in desert areas with vegetation less than 20% (Choudhury and Tucker, 1987). Such observations were made from studies using AVHRR data sets with a resolution of 1.1 km/pixel. However, Landsat TM data with a resolution of 30 m has proved to be quite effective in mapping vegetation changes in arid environments due to the high spectral and spatial resolutions. Some vegetation density would be missed because of the resolution of 30 m but the analysis gives a good order estimation of vegetation changes.

A sensitive enhancement technique such as selective PCA that was used in this study has several important applications in arid environments. By comparing several years of satellite data, anomalous trends could be detected and, if possible, remedial measures applied. The technique could be used to map potential arable land in arid environments. The areas that manifest high seasonal or inter-annual vegetation variations are most likely to support plant cultivation in the presence of abundant water. Shifting sands and sandy area can only support limited plant life even with abundant rainfall. In Kuwait, such studies a prerequisite in monitoring the resilience of the desert environment after the 1991 Gulf War. During the War, more than 50% of the desert environment were disturbed by the large-scale movement of troops, the burning of the oil wells, and post-war cleanup activities.

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