J. Agric. Sci. Mansoura Univ., 31 (9): 6103 - 6114, 2006

ASSESSMENT OF SOME ENVIRONMENTAL ASPECTS DUE TO THE SMOKE PLUME AS RESULTS OF OIL FIRES DURING 1991 GULF WAR OPERATIONS USING LANDSAT - TM IMAGE:
1 - JUBAIL AREA

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ABSTRACT

The 1991 Gulf War affected dramatically the environment of some countries in the Middle East, specially Kuwaiti, Saudi Arabia and Iraq. The military operations, crude oil release into the Arabian Gulf and burning of Kuwait's oil wells were the main causes. Remotely sensed data acquired at three different dates, namely, pre-, post-war and present times were the basic information for the current study. The results showed clearly that the areas that had vegetation loss appear to correspond with the increasing period of smoke plume from west to east of the study area. It could be stated that the vast majority of changes had occurred in the northeast and east portion of the Kingdom. The agricultural areas had experienced extreme changes where, they were affected by the soot and other fallout from the smoke plume.

INTRODUCTION

During the Gulf War of 1991, at least three types of operations were thought to create a profound environmental impact. The first was the military activities which included development of staging areas, construction activities, training drills, etc. The second activity, that caused widespread environmental damages, was the release of millions of gallons of crude oil into the Arabian Gulf. An estimated 11 million barrels of oil were intentionally released to the Arabian Gulf from January 1991 to May 1991 (Sadiq and McCain, 1993). During the peak period of war, the third environmental impact was Kuwait's oil wells fire the subsequent blowing up of nearly 700 Kuwaiti oil wells; the smoke plume was comprised of more than 5,000 tons of material daily, and covered a region 800 miles in length (Aminipouri et al, 1999). Indeed, the atmosphere was affected to large extent from the fire and smoke produced from explosives, oil fires, and from both known and unknown chemicals (Sadiq and McCain, 1993).

The current study aims to assess the changes in the terrestrial environment in the northeastern portion of Saudi Arabia where, heavy smoke coverage and some military activities of the 1991 Gulf War were pronounced, using multidates Landsat-TM data presenting three periods, namely, pre-war, near post-war and present day. The purpose of conducting the principal component analysis(PCA) is to detect changes in the terrestrial environment related to different operations of the 1991 Gulf War.

In this context, remote sensing has been used previously by researchers in the Gulf Region to detect environmental impact. They employed a variety of data types and techniques to detect change in the terrestrial environment with varying accuracies. Using AVHRR imagery, Jalali et al (1998), proved that oil pollutants were transported through the air media to Iran from the Kuwaiti oil fires. The results were illustrated through changes in biomass. Aminipouri et al (1999), chose to use AVHRR as data and normalized difference vegetation index(NDVI) as a detecting technique due to the regional scale of the study area, accuracy and workability of the data for detecting vegetation change. While, Kwarteng and Chavez (1998) reported that a "change detection image" composite, made from the individual change image results generated using TM bands -2, -4, and -7, detected and mapped temporal changes dealing with urban development, vegetation, coastal wetlands, and sand sheet surface differences caused by the large oil spill that occurred during the 1991 Gulf War at the Greater Burgan oil. Abuelgasim et al, (1999) addressed the application of neural networks for change detection. The results showed that a newly developed neural network approach resulted in an accuracy of 86% compared to an accuracy of 70% for a more standard multidate K-means algorithm and 65% generated by an analogous maximum likelihood classifier approach. However, three different data types which included the maximum 10 day composite NDVI time series (NOAA-GAC), time series daily (NOAA-AVHRR) and time sequential Landsat-TM images were also examined. These data were processed, interpreted, and combined in a geographical information system (GIS) environment. Results from the NDVI profiles analysis indicated a considerable drop in peak profiles in 1991 and a decrease in the vegetation maturation period for the years prior to the introduction of pollution. Additionally, the NDVI profiles revealed a sharp drop in the senescence period of the growth profiles which was temporally coincident with the occurrence of polluted rainfall.

Principal component analysis (PCA) is an image enhancement technique that has been used primarily as a data compression tool. PCA removes data redundancy usually common in image bands that appear similar and convey essentially the same information. Several workers (Lodwick, 1979; Byrne et al, 1980; Richards, 1984 and Singh, 1986) had also applied this technique for land-cover change detection using remotely sensed data. This technique is employed, in the current study, to extract significant terrestrial changes from different Landsat-TM scenes at various three dates.

MATERIALS AND METHODS

Study Area

The Jubail area is located in the northeastern portion of Saudi Arabia at the Arabian Gulf, (Fig., 1). The study area was heavily affected by greatest smoke concentration for long period as well as military activities at different degrees. Figure 1 shows the location of the selected TM image (165/41), the smoke plume contours and arrows representing military activities. The smoke plume contour lines are illustrated, from east to west, representing 10, 25, 50, 100, 150 and 200 day coverage periods.

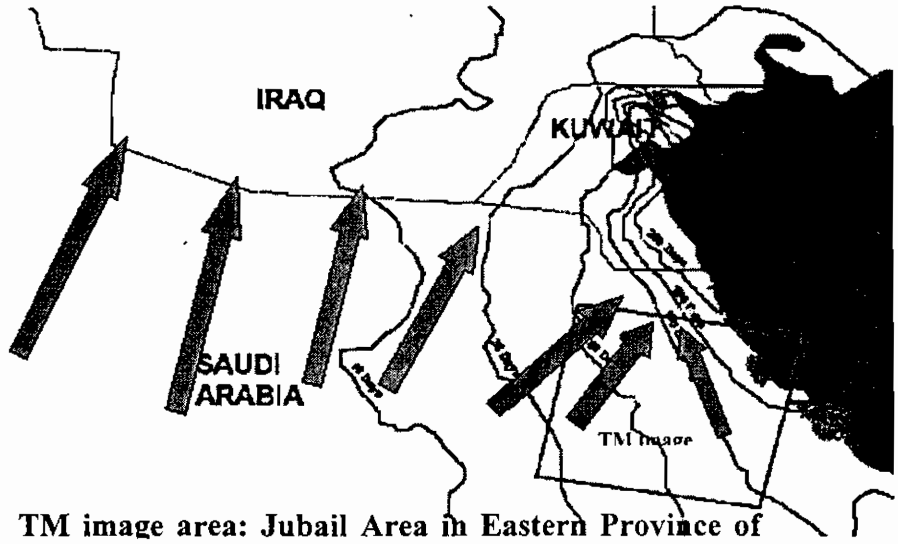


Figure 1: Map of the study area showing location of the selected TM image, smoke plume contours (in magenta), and military activity arrows (in cyan).

Materials

Ideally, the selected three dates of Landsat-TM. imagery for the study area would be the same for each year to reduce changes due to seasonal differences from one year to another. The dates (Tab., 1) used in this study were all within the spring growing season and should be adequate.

Table 1: List of the three dates of the used TM imagery used.

Image Path/Row	Pre - War	Post -War	Current
165 / 41	28 Feb. 1990	18 Feb. 1992	2 Feb. 2001

Whenever single dates of imagery are compared in order to map the location of change, there is a risk that either or both dates of imagery may contain non-representative conditions because of sudden events. Recent rain events, for example, could cause significant short-term changes to vegetation and darkening of soil or sand. Recent or extreme rainfall, surface winds that blowing sand, atmospheric conditions, and temperature can all cause non-representative conditions.

Sparse desert and rangeland vegetation may be difficult to measure with TM imagery because it commonly occupies only a portion of the pixel. Military activity features less than 30 m in size may also be difficult to detect.

Three change detection products were generated for the elapsed periods 1990-1992, 1992- 2001, and 1990-2001. These products map location and extension of change across the study area for each time series pair. The final change detection products will be georeferenced map products showing the location and extent of significant change over the study area.

Methodology

The three dates of TM imageries were processed in the same way so that results can consistently be compared within the image area. Also, all images were evaluated for anomalies, artifacts, and image quality.

A prerequisite for mapping change in multi-temporal imagery is image-to-image registration to align pixel locations in any two registered images. Therefore, the 1990 and 1992 images were spatially registered to their corresponding 2001 image. For each image-to-image registration, 25 to 35 control points, homogeneously distributed over the entire scene footprint, were carefully selected using intersections between well defined, invariant linear features on both images. This registration was carried out using ERDAS IMAGINE software and a second-degree polynomial transformation with an overall error of less than one pixel for each pair of registered images. Another important factor that could significantly affect the change identification is the differences in atmospheric and/or illumination conditions among the multi-date images involved in the process. To minimize detected change due to these factors, the 1990 and 1992 images were normalized to their corresponding 2001 images to remove variations due to atmospheric effects and sun angle differences. The normalization involves an empirical line correction and linear regression analysis. Additionally, all imagery was color balanced for visual display and analysis purposes using standard ERDAS IMAGINE tools.

Principal Component Analysis (PCA) is an image enhancement technique that is used to compress information in the six relative TM bands into a smaller number of bands. PCA removes data redundancy usually common in image bands that appear similar and convey essentially the same information.

Various techniques are available to identify, quantify, and map change. The preliminary results presented in this paper have been generated using a conventional Principal Components Differencing (PCD) technique.

It is the process of subtracting the PCA of one date from the PCA of another date and of thresholding (assigning colours) the most significant values of change. For each of the two TM image areas, PCD results were generated for three time periods; 1990 to 1992, 1992 to 2001, and 1990 to 2001. The change detection results show the location and extent of change across the entire TM image area. Each set of change results were analyzed extensively and the results from one time period to another were compared and evaluated.

RESULTS AND DISCUSSIONS

The TM image (165/41) covers an area called Jubail which is located along the Saudi/Arabian Gulf coast where there were heavy smoke coverage and some military activities during the 1991 Gulf War. Figure 2 shows the raw data of 1990 and 1992 images displayed as colour composite of bands 3,2,1 rendered in RGB, respectively. The dark areas in the west central and southeastern portions of the image were agricultural fields. Visual comparison of these two images reveals that many areas, especially in the north and east of the image, got darker in 1992. They were distinct and well defined on the 1992 image. The areas that were getting darker appear to correspond with the increasing period of smoke plume from west to east across the image at 50 days up to 200 days.

Feb. 1990 **Feb. 1992**

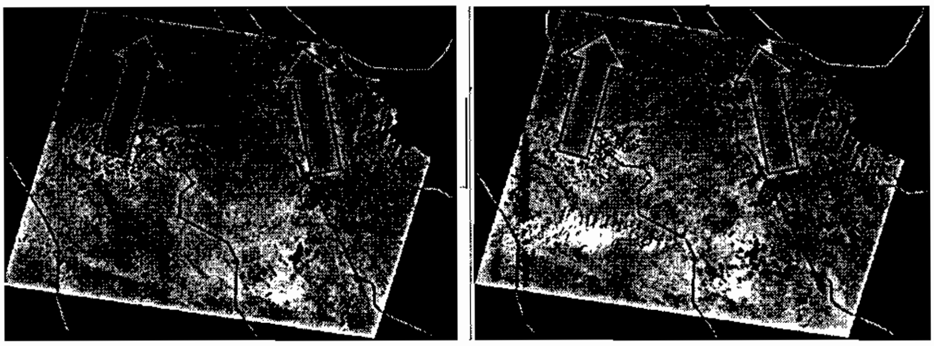


Figure 2: Image raw data of Jubail region as a colour composite (bands: 3,2,1 in RGB) from 1990 and 1992 with smoke plume contours (in magenta) and military activity areas (arrows in cyan).

The detected changes between the 1990 and 1992 images by applying the PCD technique are shown in figure 3. Areas that had become darker in 1992 are coded in red and yellow, with red being the most significant. The concentration of yellow correlates with the smoke plume contours. It is suspected that the darkening in 1992 was the result of soot and other smoke plume fallout from the burning oil fires in Kuwait. Blue and cyan indicate areas that had become brighter in 1992, with blue being the most significant. The agricultural areas that appear in the west central portion of the image had experienced extreme changes. These changes reflect new fields or changed conditions in the large circular pivot irrigated fields. Concerning the change results for the whole area covered by this image, it could be stated that the vast majority of changes had occurred in the northeast and east sections.

An enlargement of the northeastern section which is the main area of interest (Fig., 4) showing areas of most significant negative change (darkened) that were coded in red. These were primarily located between the 150 and 200 (maximum) day smoke plume contours and were surrounded by areas coded in yellow. The red areas are suspected to contain the most soot and smoke plume fallout material on February 18, 1992.

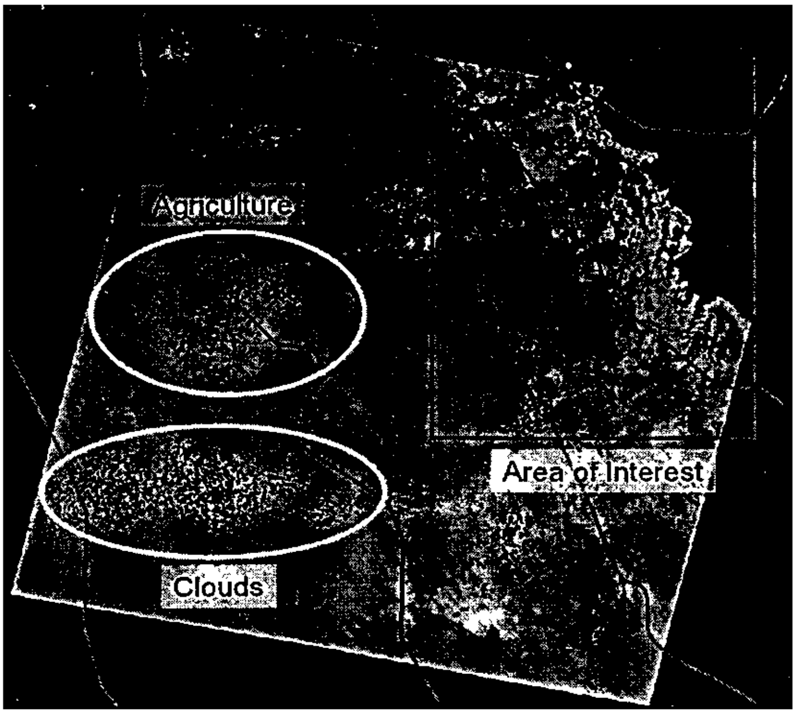


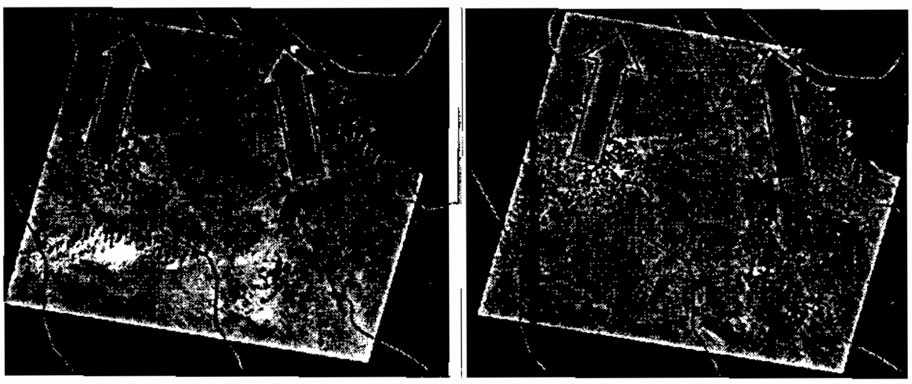
Figure 3: Change detection for the full TM image between 1990 and 1992 using PCD.

Figure 4: Enlargement of the northeast area of the TM image illustrating changes between 1990 and 1992.

Several dark areas, which are coded in cyan, indicate areas that became brighter in 1992. These could be areas of recently deposited sand or areas that had experienced vegetation loss.

Figure 5 shows the 1992 and 2001 raw TM full scene displayed as colour composite of bands 3, 2 and 1 rendered into R, G and B, respectively. Many of the distinctive dark areas in 1992 were not dark in 2001. These dark areas in 1992 appeared in 2001 as natural desert sand common to most of the area covered by the image. An enlargement of the northeast section of the image (figure 6) shows the change detection results from 1992 to 2001 and indicating the area of most changes. The majority of such changes were significantly positive, where the areas (shown in cyan) had brightened with the time. A possible explanation is that, these areas were brighter in 2001 because the soot that made them dark in 1992 had moved away in 2001, exposing the bright sand. These bright areas also are correlated with the smoke plume contours.

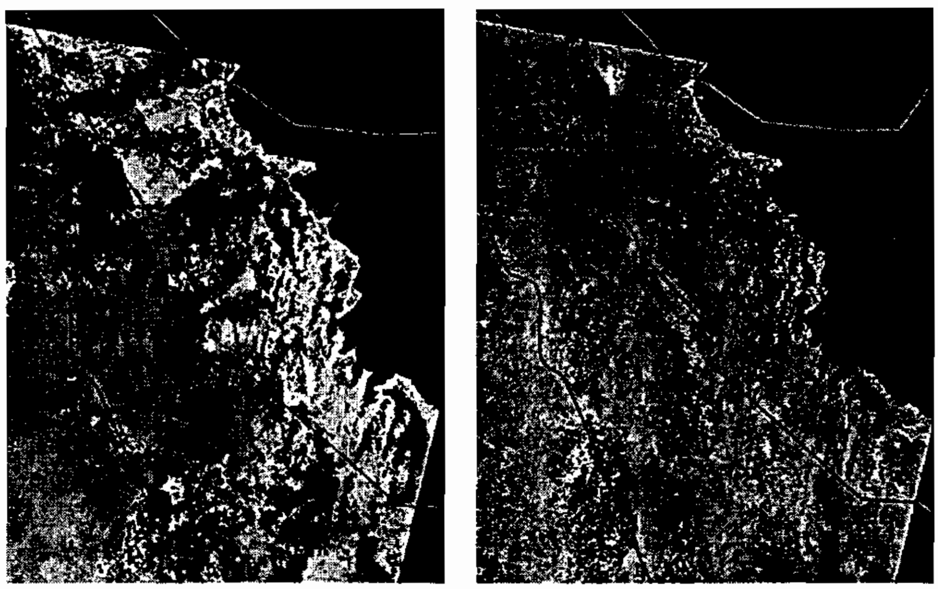
The changes from 1990 to 1992 and from 1992 to 2001 are illustrated in figure 7. Many of the areas that were dark in 1992 became bright in 2001. This may be due to eolian and other natural weathering processes that restored the area to its original surface condition.



Feb. 1992 **March 2001**

Figure 5: Image of Jubail showing smoke plume contours (in magenta) and military activity areas (arrows in cyan) displayed on raw images (RGB: 3,2,1) from 1992 and 2001.

Figure 6: Enlargement of the northeast area of the TM image illustrating change between 1992 and 2001.



1990 to 1992 | 1992 to 2001

Figure 7: Comparison of 1990 to 1992 and 1992 to 2001 change detection (PCD) results.

The full scene of 1990 and 2001 raw TM bands 3,2 and 1 rendered into R,G and B, respectively (Fig., 8), shows the changes from before the Gulf War to the near present. There are distinct dark regions on 2001 image and they correspond roughly in size and location to dark areas of the 1990 image.

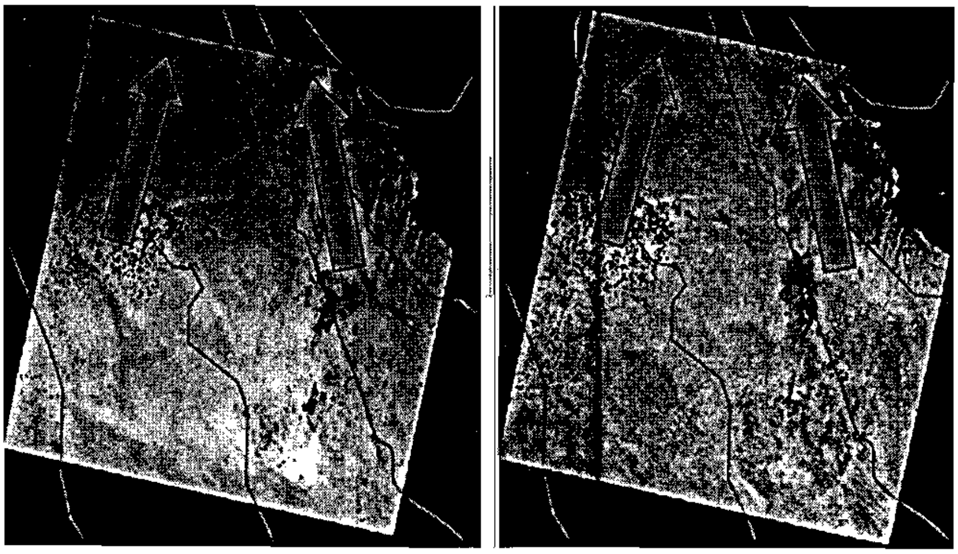
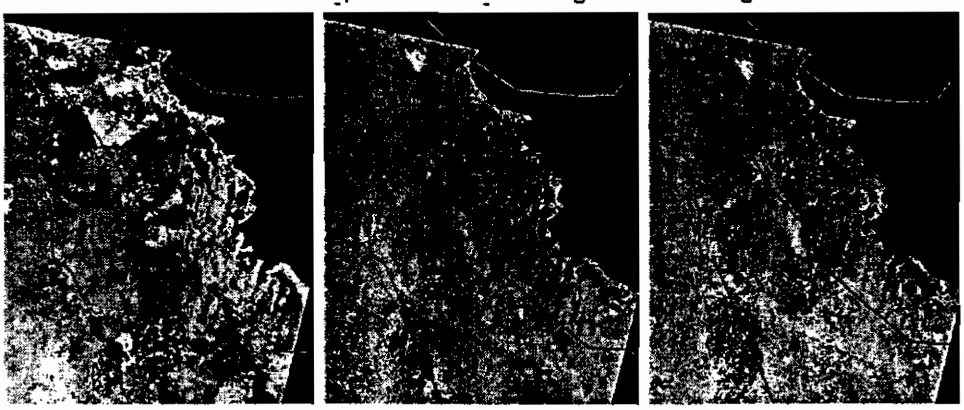


Figure 8: Image of Jubail showing smoke plume contours (in magenta) and military activity areas (arrows in cyan) displayed on raw images (RGB: 3,2,1) from 1990 and 2001.

Figure 9: Enlargement of the northeast area of the TM image illustrating change between 1990 and 2001.

The enlargement of the same northeastern section is illustrated in figure 9 showing the change detection results for 1990 - 2001. This part of the image covers the area of most change. The change occurred in relatively small areas. These areas became brighter in 2001. The amount of change from 1990 to 2001 was substantially less than the change measured between 1990 to 1992 and 1992 to 2001. This indicates that the surface conditions of most areas in 2001 were similar to the conditions in 1990. It also implies that the environment had, to a large extent, rebounded back from the widespread darkening experienced immediately after the War.

The change detection (PCD) results for the three time periods: 1990 - 1992, 1992 - 2001, and 1990 - 2001 are illustrated in figure 10. The amount of change in the period 1990 - 1992 and 1992 - 2001 (left and middle images) exceeded that noticed between the years 1990 and 2001 (right image). Also, the amount of change in the two years between 1990 and 1992 was much greater than that occurred in the nine year 1992 - 2001 period. This reveals that the darkening of the ground surface happened very quickly from the year 1990 to 1992 and the subsequent brightening, which mean the restoration of the environment towards its original condition, had taken a lot longer. Although the environmental conditions of the land surface in 2001 was much closer to that in 1990, there were still local areas were brighter and few that were darker than in 1990. Many of the areas that were darker in 2001 than 1990 are coded in red and represent the most significant change.



1990 to 1992 1992 to 2001 1990 to 2001

Figure 10: Change detection comparison of the three time periods using PCD for the TM image.

CONCLUSION

Many areas where, change resulting from smoke coverage, were detected. The change detection (PCD) results for Jubail region were shown for 1990 to 1992, 1992 to 2001, and 1990 to 2001. The most change occurred in 1990 to 1992 where, there was significant darkening of major areas. These areas are suspected to contain soot and other fallout from the smoke plume, causing them to appear dark. In 1992 - 2001, there was a brightening up of many areas that got darker in 1990 to 1992. These areas were assigned as they had significant change. The change from 1990 to 2001 indicates that most of the region was back to the condition it was in 1990.

Acknowledgments

This study was a part of an intensive study that was funded by The Presidency of Meteorology and Environment (PME) and Environmental consulting Bureau (ECB). The authors acknowledge their support. Thanks are also due to the anonymous reviewers for their valuable comments and critical revision of the manuscript.

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تقييم بعض المظاهر البيئية الراجعة للأدخنة المتصاعدة نتيجة لحرق البترول أثناء حرب الخليج عام ١٩٩١ بإستخدام مرئيات القمر الصناعى لاندسات: ١- منطقة الجبيل

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أثرت حرب الخليج ١٩٩١ تأثيرا بالغا فى بيئة بعض أقطار الشرق الأوسط و خاصة الكويت و المملكة العربية السعودية و ايران، و لقد كانت الأنشطة العسكرية و تسرب الزيت الخام إلى الخليج العربى و حرق حقول البترول من المسببات الرئيسية لهذا الأثر البيئى. و لقد إعتمدت الدراسة على مرئيات القمر الصناعى لاندسات فى أزمنة متعددة (قبل و بعد الحرب مباشرة و الوقت الحالى) كمصدر أساسى للبيانات. و لقد أوضحت نتائج هذه الدراسة أن المناطق التى تعرضت لفقد الغطاء النباتى تتطابق مع زيادة فترة التعرض للأدخنة من الغرب للشرق بمنطقة الدراسة، على أن التغيرات الرئيسية حدثت فى المناطق الشمالية الشرقية و الشرقية من المملكة و كان التأثير الحاد واقعا على الرقعة الزراعية حيث تأثرت بشدة بالسناج و المتساقطات الأخرى لأدخنة حرق البترول.