J. Agric. Sci. Mansoura Univ., 31 (9): 6115 - 6128, 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:
2- RAS AL KHAFJI OF THE EASTERN PROVINCE OF SAUDI ARABIA AND SOUTH OF KUWAIT

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ABSTRACT

The present study aims at assessing the impact of the 1991 Gulf War on the terrestrial environment of Ras AL Khafji in Eastern Province of Saudi Arabia and an area south of Kuwait. Landast-TM imageries acquired at three various dates are the main source of information. The most negative changes occurred between the year 1990 and 1992 where, the extensive vegetation noted in the study area in 1990, was almost gone in 1992. These areas of significant negative change were affected by the most soot and smoke residual. However, the positive changes were detected in the year 2001 where, the vegetation appeared again in the same locations. The results of the current study indicate that most of the region under investigation was back to the condition of the year 1990.

INTRODUCTION

Three factors, at least, could be considered as reasons of the pronounced environmental impact of the 1991 Gulf War. Military activities, including development of staging areas, construction activities, training drills, etc., were the main threatening factor. Widespread environmental damages occurred by the release of millions of gallons of crude oil into the Arabian Gulf. Where, approximately 11 million barrels of oil were released from January 1991 to May 1991 (Sadiq and McCain, 1993). The third factor of the 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). The air was polluted from the fire and smoke produced from explosives, oil fires, and from both known and unknown chemicals (Sadiq and McCain, 1993).

The present study aims to assess the changes in the terrestrial environment of Ras AL Khafji in Eastern Province of Saudi Arabia and an area south of Kuwait where the area had experienced heavy military activities and the longest period of smoke coverage of the 1991 Gulf War. Multidates Landsat-TM data presenting three periods, namely, pre-war, near post-war and present day were the main source of information. The purpose of conducting PCA analysis is to detect changes in the terrestrial environment related to different operations of that Gulf War.

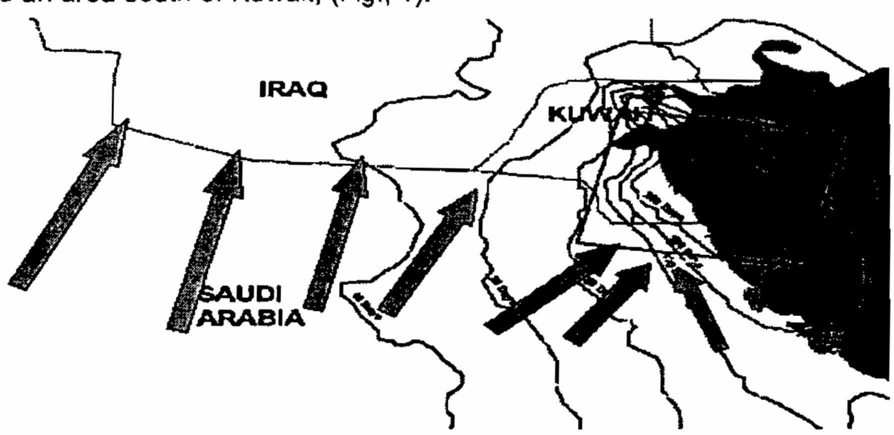
Remote sensing has proved to be valuable for detecting the environmental impact of the war in the Gulf Region. Aminipouri *et al.* (1999), used AVHRR data and the Normalized Difference Vegetathon Index (NDVI) technique because of the regional scale of the study area, accuracy and workability of the data for detecting vegetation change. However, Kwarteng and Chavez (1998) proposed 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 caused by the large oil spill and fire that occurred during the 1991 Gulf War at the Greater Burgan oil. Moreover, 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. The results showed 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.

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.

MATERIAL AND METHODS

Study area

The study area is Ras AL Khafji in Eastern Province of Saudi Arabia and an area south of Kuwait, (Fig., 1).



TM Image Area: Ras AL Khafji in Eastern Province of Saudi Arabia and area south of Kuwait

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

Location of the selected TM image (165/40), the smoke plume contours and arrows representing military activities are shown. The satellite image covers a region that had experienced heavy military activities and the longest period of smoke coverage of the 1991 Gulf War. The smoke plume contour lines are illustrated, from east to west, representing 10, 25, 50, 100, 150 and 200 day coverage periods.

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 variation 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.

Image Path/Row	Pre - War	Post -War	Current
165 / 40	28 Feb. 1990	18 Feb. 1992	06 March 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 of the study area were processed in the same way so that results can consistently be compared within an image area and between image areas. 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 multidate 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 (165/40) covers the northeastern portion of the study area Ras AL Khafji and south of Kuwait .which was the most area that experienced heavy military activities and the longest period of smoke coverage. Figure 2 shows the colour composite of full TM image bands 5, 4 and 3 rendered in R, B and G, respectively. The massive oil fields burning in Kuwait appear as large dark blotches with heavy smoke deposition extending from the northwest to the southeast of the terrestrial portion of the image.

Figure 12 contains three enlargements of the TM image covering northeastern Saudi along the Kuwait border. The 1990, 1992, and 2001 raw TM images are displayed as false colour composite of TM bands 5, 4 and 3 coded in R, G and B, respectively, and thus, vegetation appears green and sand appears white. No change detection results are shown on these images. The variations from one date to another are due to different surface conditions measured by the sensor.In figure 3, the extensive vegetation noted in the Saudi study area in 1990, was almost gone in 1992. This vegetation reappeared in the same locations in 2001. The apparent increased vegetation along the Kuwait border in 2001 as compared to 1990 may be due to more favorable growing conditions during the weeks before the 2001 image was acquired, when they were compared to the conditions in 1990. Many areas on the 1992 image, were much darker than on 1990 one, especially in a wide band along the coast. The dark areas were suspected to contain soot from the smoke plume fallout. This was most evident in Kuwait where the smoke originated. The dark areas in the image correspond to areas covered by smoke plume for the longest period as depicted by the smoke contours. In 2001, many of the extensive darkened areas of 1992 had returned to their 1990 brightness levels. It could be explained that the soot and other residuals from the smoke, that caused the sand and vegetation to be darker in 1992, had weathered away and were not detectable on the surface. There were, however, major local areas that were very dark in 2001 but not dark in 1990. These areas could still contain material deposited from the smoke or could be depositing areas for this material.

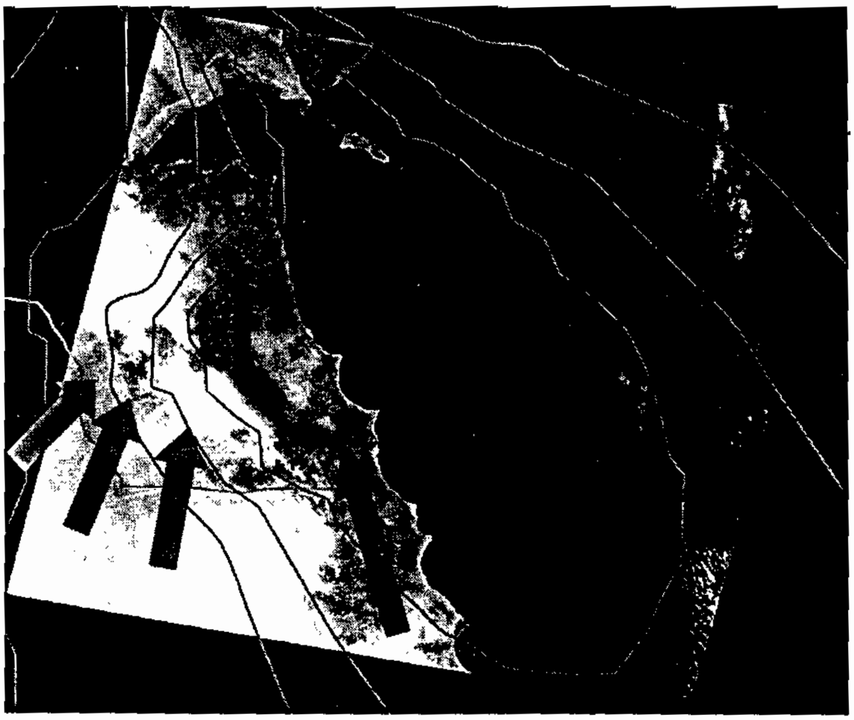


Figure 2: The studied image showing smoke plume contours (in magenta) and military activity areas (arrows in cyan) displayed on the raw image (R, G and B: 3, 2 and 1) from 1992. The image also shows the smoke deposition extending from northwest to southeast, which corresponds to the smoke plume contours.

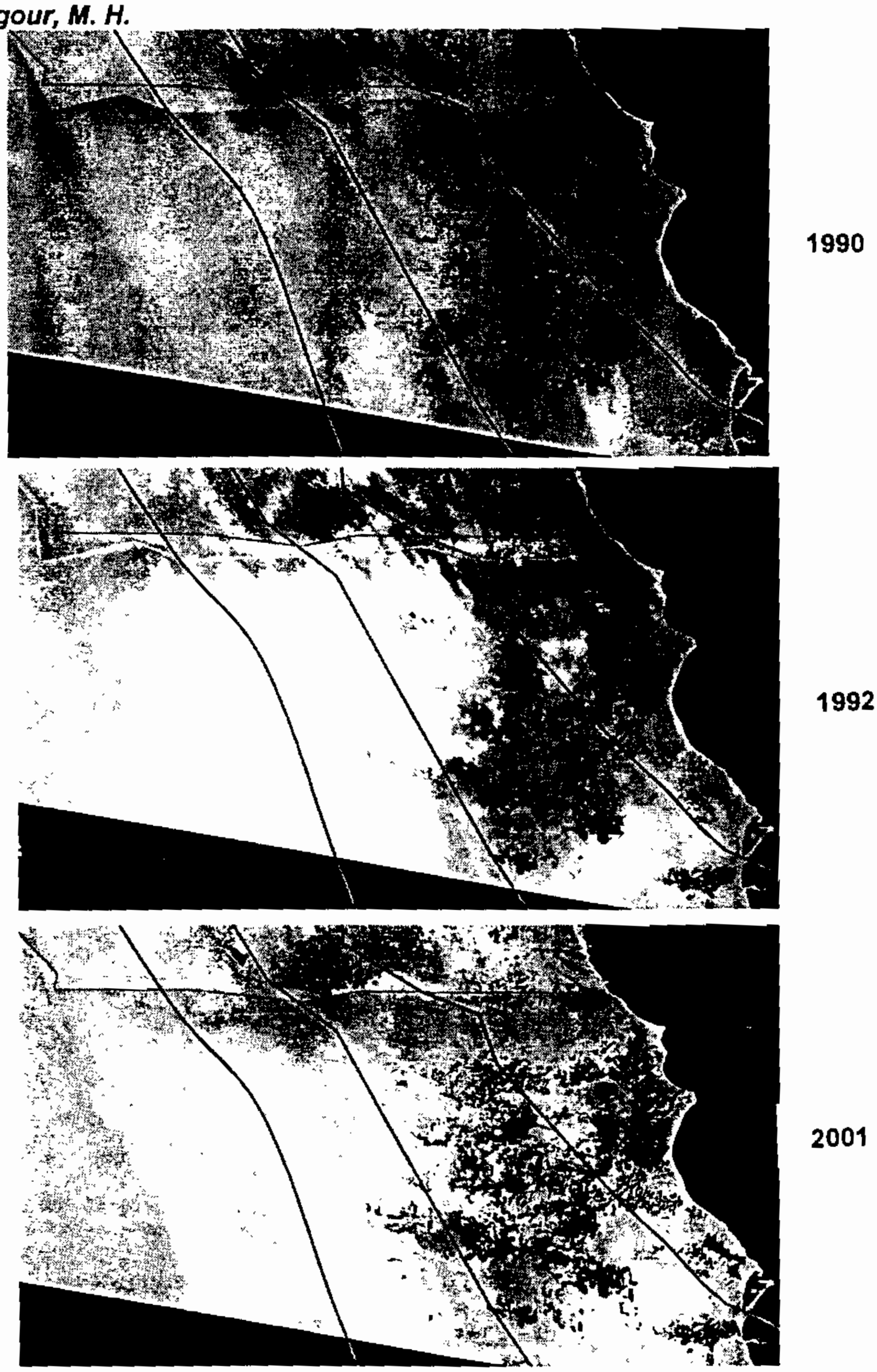


Figure 3: Enlargements of the image covering northeastern Saudi along the Kuwait border. The 1990, 1992, and 2001 raw TM images are displayed sequentially (in R, G and B: 5, 4 and 3) for visual comparison.

The enlarged parts of the image along the Kuwait border on the Arabian Gulf coast, (Fig., 4-a), are raw images of 1990 (top) and 1992 (bottom). Both images are displayed in combination of bands 5, 4 and 3 rendered into R, G and B, respectively in order to show vegetation in green. As it could be noticed in figure 3, the 1990 vegetation disappeared in 1992.

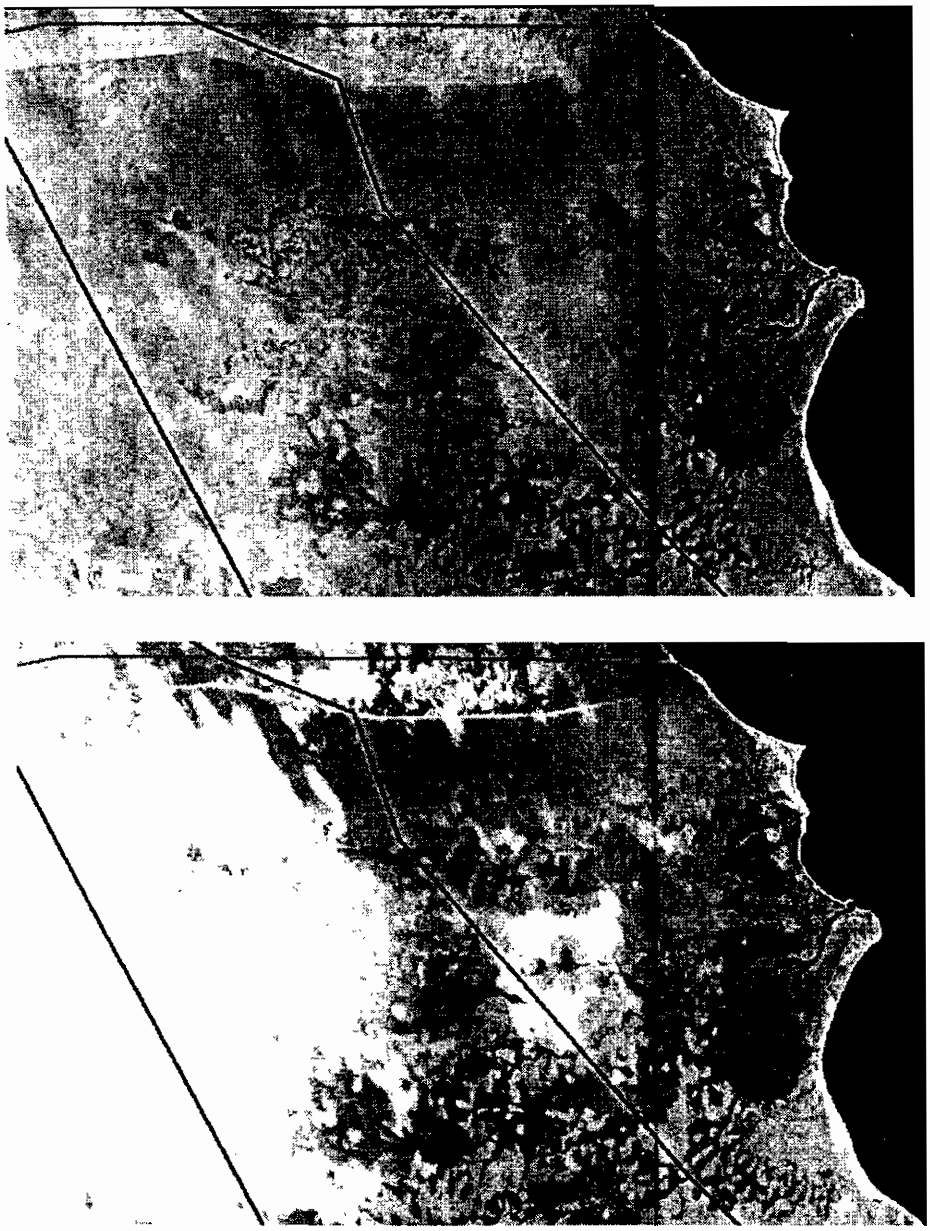


Figure 4-a: Enlargement of studied image shown in figure 3, 1990 (top) and 1992 (bottom) band combination 5, 4 and 3.

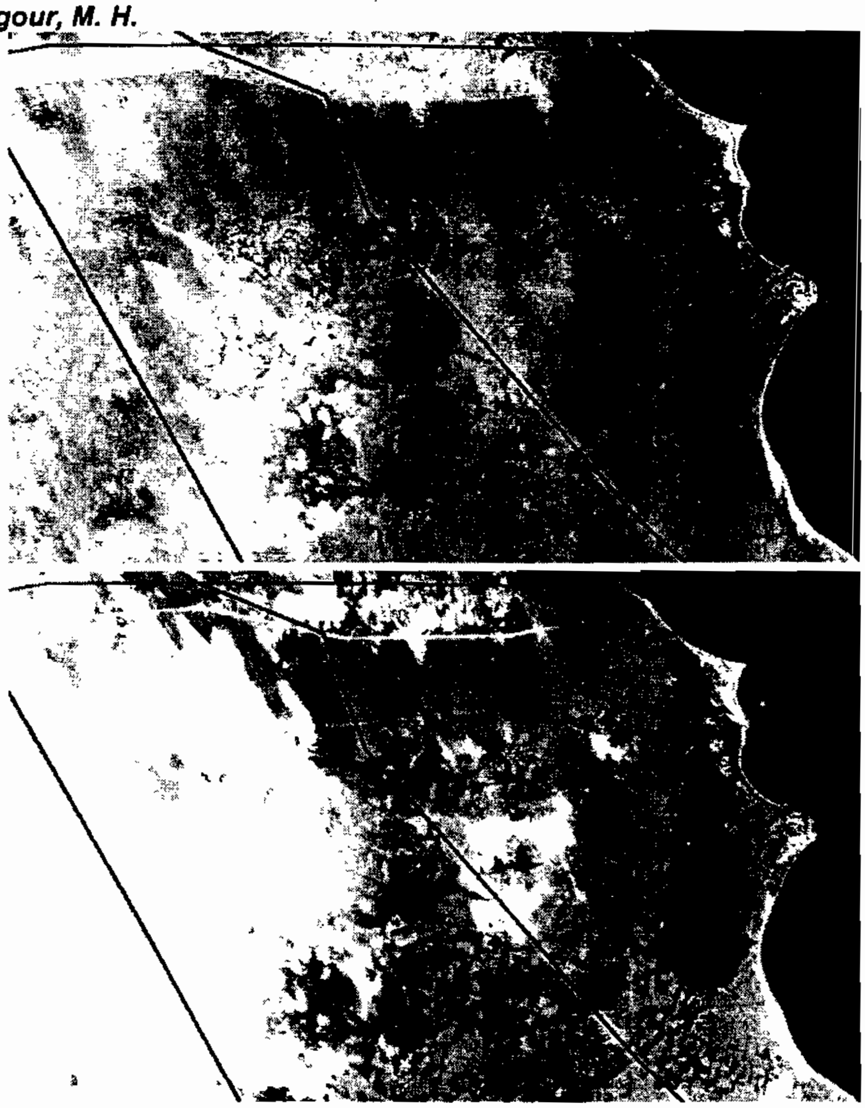


Figure 4-b: Enlargement of the studied image shown in figure 3, 1990 (top) and 1992 (bottom) band combination 3, 2 and 1.

Figure 5 shows the image that covers the same area as in figure 3 and 4, illustrating the change detection (PCD) results between the years 1990 and 1992. The yellow colour indicates the areas of significant negative change (darkening) and corresponds well with the areas in figure 3 that had darkened. It is suspected that on February 18, 1992, these areas of significant negative change was affected by the most soot and smoke residual. It should be mentioned that, there were some areas of most significant negative change coloured in red, but these were all in Kuwait. Also, large areas to the west had become brighter shown in cyan. These could be areas of recent deposited sand. If the stabilizing vegetation in these areas was destroyed, the sands could be more mobile.

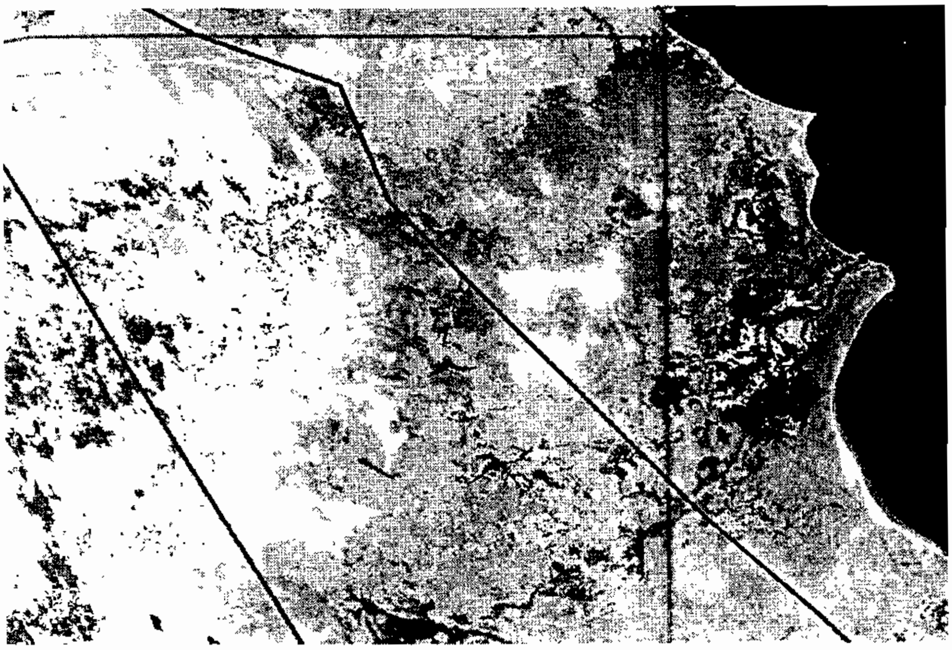


Figure 5: Enlargement of the northeast area illustrating change between 1990 and 1992 displayed on 1992 image.

Figure 6 shows the 1992 and 2001 raw image bands 5, 4 and 3 rendered in R, G and B of the same enlarged area, where vegetation appears green. There was an extensive, wide band of vegetation along the Kuwait border in the 2001 image. This area had no vegetation and was very dark in the 1992 image. The change detection (PCD) results for the period 1992 – 2001, (Fig., 7), show that many of the areas that became darker from the year 1990 to 1992, got brighter between 1992 and 2001. This is what could be called the rebound effect.

The raw data of the 1990 and 2001 image bands 5, 4 and 3 rendered in R, G and B, respectively is shown in figure 8. The areas that had vegetation in 1990 (green) also had vegetation in 2001. There were apparently more vegetated areas in 2001 than in 1990. These may be due to more favorable growing conditions in the weeks before the 2001 image acquisition as compared to the 1990 image. There were many more well defined dark areas in the 2001 image. The dark areas in 2001 were much more extensive than in 1990. The change detection (PCD) results for the period 1990 – 2001, (Fig., 9), reveals that, there was a band of yellow (significant darkening) along the border of Kuwait. This area was probably darker in 2001 either because it contained soot and fallout from the smoke or because of grown vegetation. The larger eastern area seemed to have increasingly grown vegetation whereas the central and eastern areas (east of the 150 day smoke contour) could be from soot and smoke fallout.


1992

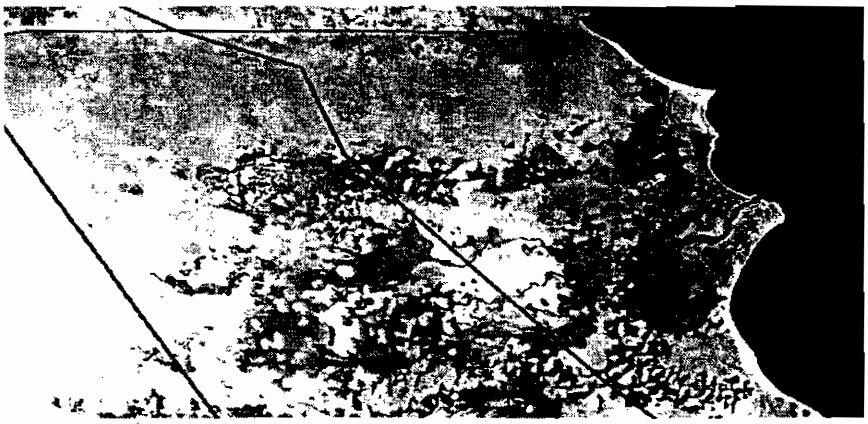
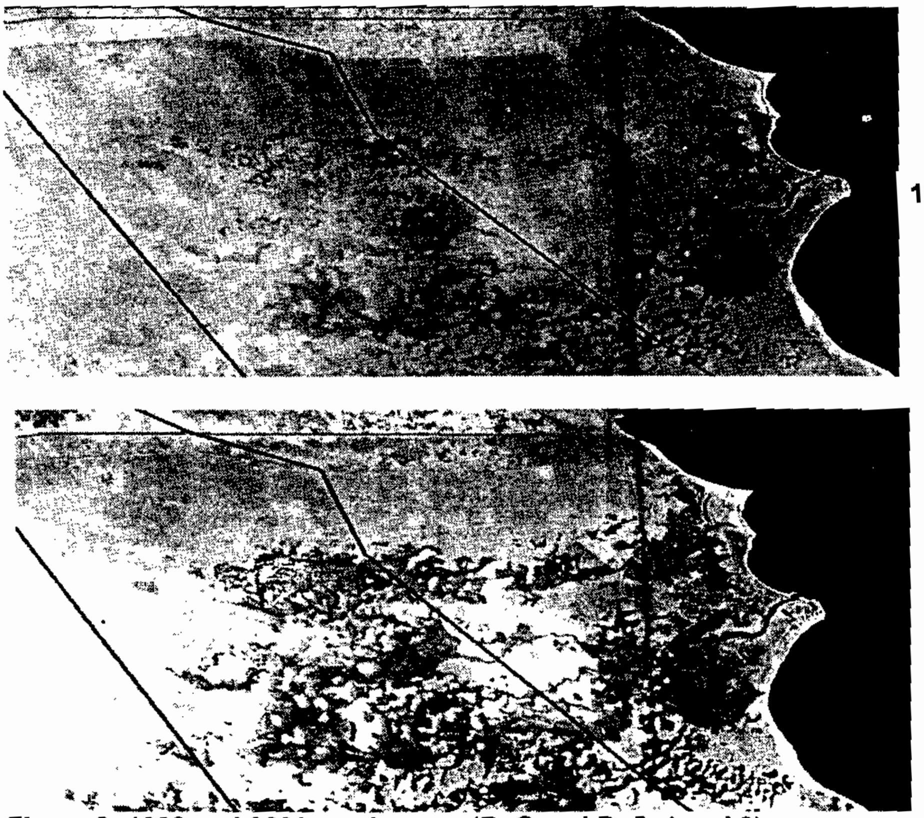

2001

Figure 6: 1992 and 2001 raw images (R, G and B: 5, 4 and3) for the same northeast area enlargement.

Figure 7: Change detection (PCD) results for 1992 to 2001 displayed on 2001 image.



1990

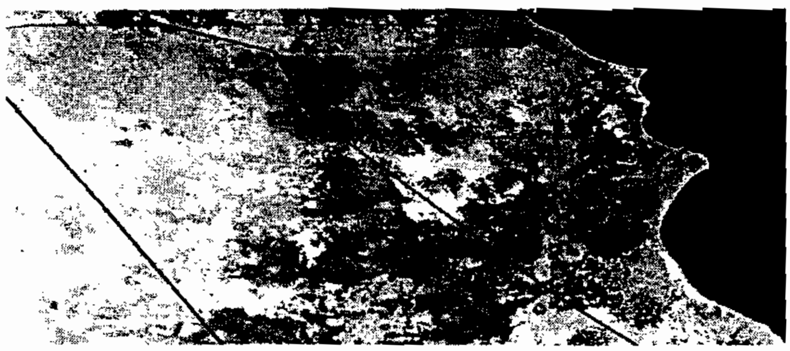
2001

Figure 8: 1990 and 2001 raw images (R, G and B: 5, 4 and 3).

Figure 9: Change detection (PCD) results for 1990 to 2001 displayed on 2001 image.

Figure 10 shows the change detection (PCD) results for all three time periods. In summary, this area experienced extensive darkening in 1990 to 1992 as a result of smoke fallout. In 1992 to 2001 many of the darkened areas became bright. This was probably due to soot weathering and thus, exposing sand. The net change results over this 11 year period (1990 to 2001) showed that many areas were darker in 2001 than they were in 1990. It is suspected that this darkening was lingering effects of smoke fallout.


1990 – 1992


1992 – 2001

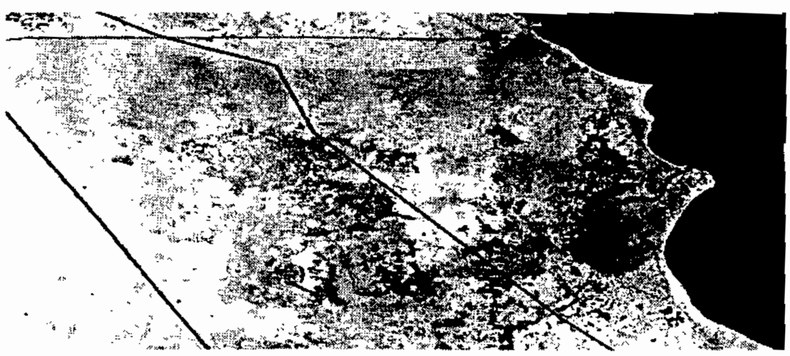

1990 - 2001

Figure 10: Change detection comparison for the three time periods.

Conclusion

There were many areas where change resulting from smoke coverage has been detected. The .change detection (PCD) results for the TM Image 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 obtained results clearly indicate that most of the region under investigation was back to the condition of the year 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:
٢- منطقة رأس الخفجى بالمنطقة الشرقية للمملكة العربية السعودية و جنوب الكويت

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تهدف هذه الدراسة إلى تقييم أثر حرب الخليج ١٩٩١ على البيئة الأرضية لمنطقة رأس الخفجى بالمنطقة الشرقية للمملكة العربية السعودية و منطقة جنوب الكويت. مرئيات القمر الصناعى لاندسات المأخوذه فى ثلاث أزمنة متعددة (قبل و بعد الحرب مباشرة و الوقت الحالى) هى المصدر الأساسى للبيانات المستخدمة فى هذه الدراسة. أوضحت الدراسة أن أهم التغيرات السلبية حدثت فى الفترة بين عامى ١٩٩١ و ١٩٩٢ ، حيث أن الغطاء النباتى الكبير الملحوظ فى عام ١٩٩٠ قد إختفى تقريبا فى عام ١٩٩٢، إذ قد تأثرت هذه المناطق ذات التغير السلبى المعنوى بالسناج و بقايا الأدخنة. إلا أنه قد تم رصد التغيرات الإيجابية فى عام ٢٠٠١ حيث ظهر النبات مرة أخرى فى نفس المواقع. كما تشير نتائج هذه الدراسة إلى أن معظم المناطق تحت الدراسة قد عادت لى الظروف التى كانت عليها فى عام ١٩٩٠.