CHANGE DETECTION ON NATURAL VEGETATION COVER IN THE TERITORY OF I.R. OF IRAN CAUSED BY POLLUTION RESULTED FROM THE KUWAITI OIL WELL FIRES, DURING THE PERSIAN GULF WAR

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KEY WORDS: Image processing, Change detection, Persian Gulf war, vegetation cover

ABSTRACT

Burning of nearly 700 Kuwaiti oil wells and storage tanks during the Persian Gulf war made a severe impact on the environment of the region by emitting about 5000 tons of smoke daily. The fall out of smoke plumes in forms of dry and wet deposition reached even to the center and north of Iran. The majority of the rich and productive rangelands in the southern parts of Iran were strongly marked by pollution to various degrees. Generally, the polluted rainfall was spread over the whole natural vegetation in 1991. Since nobody was prepared to record the impact and consequence of that environmental catastrophe, So, remotely sensed data were selected as a good information source to assess the short term effect of the pollution on the natural vegetation cover. For this study, out of various change detection techniques, spectral change analysis method with special emphasis on vegetation indices was selected. The NDVI (*Normalised Difference Vegetation Index*) was used for natural vegetation cover change detection in this study because of its acceptable accuracy and ability to detect the green vegetation. To a certain extent of decision, the methodology was made on the basis of availability of data, particularly the satellite images.

As a result, it was found that integrated use of remotely sensed images with different resolutions also with support of available ground data and statistical analysis is reliable approach to detect the impact of environmental pollution on vegetation cover, particularly when the event is not accessible in term of time. This study showed that natural vegetation cover was significantly decreased in the areas which have been affected by pollution during the Persian Gulf war.

INTRODUCTION

Two specific events that occurred during the Persian Gulf War made a severe impact on the environment of the region. In late January 1991, millions of barrels of crude oil were released into the Persian Gulf from tankers and oil terminals located off the coast of occupied Kuwait. Less than one month later, nearly 700 Kuwaiti oil wells, storage tanks, refineries and facilities were blown up and set on fire. An estimated nine hundred million barrels of oil were burned or spilled onto the land and water during the following nine months, generating trails of smoke and soot. During the peak period of the fires, the wells were emitting about 5,000 tons of smoke daily in a plume over 800 miles long, which covered Iran and the neighbouring countries. The fall-out of the smoke plumes reached up to centre and north of Iran and the Persian Gulf region in forms of dry and wet precipitation.

Reports in the media, records on polluted rain, some field observations, interviews with local experts, published reports for instance the work by NCAR and the earlier study on tracking of smoke plumes (see chapter 2) strongly prove the transport of the pollution into the territory of the I.R. of Iran. (Jalali *et al*, 1998), see also plate 1.

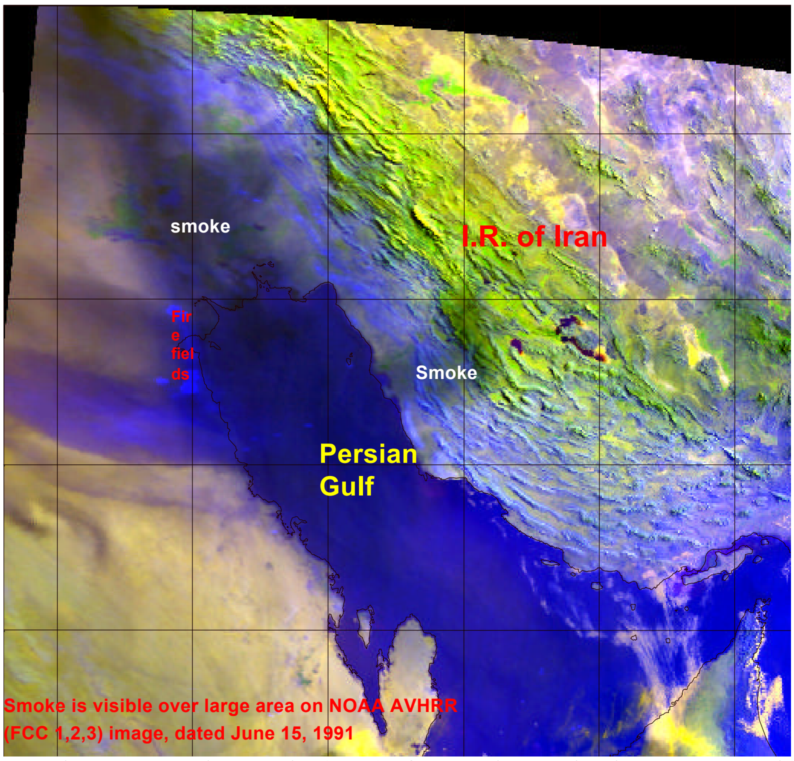


Plate 1: False Color Composite Image Band 1, 2 and 3 (RGB) of NOAA image dated June 15, 1991 shows heavy smoke persistence over Iran and Kuwait. (After SCWMRC, 1998).

The majority of the rich and productive rangelands in south parts of Iran were strongly marked by pollution in various levels [Heidari, 1998]. Generally, the polluted rainfall and fall-out of the smoke plumes as a result of the Persian Gulf War, spread over the whole natural vegetation cover in 1991. Although it is difficult to fully evaluate all aspects of the pollution on the vegetation cover, some aspects of such pollution were investigated in this study.

OBJECTIVE

The main objective of this study was to assess the short term effect of the pollution on the natural vegetation cover using remotely sensed data in the study area in terms of change of *green biomass* and establishment a relationship between the changes on vegetation cover and the pollution. After tracking the smoke plumes, the changes in green vegetation cover of the rangelands contaminated by regional and wide spread polluted rainfall and the fall-out from smoke plumes were studied.

METHODOLOGY

According to literature, there is no strongly advised optimal change detection techniques exist for natural vegetation cover: the choice is dependent upon the application because there is still conflict between the results of quantitative comparative studies of change detection techniques. Even the question of which is the best for any particular application, remains generally open.
For this study, out of various change detection techniques, spectral change analysis method with special emphasis on vegetation indices was selected. The NDVI (*Normalised Difference Vegetation Index*) was used for natural vegetation cover change detection in this study because of its acceptable accuracy and ability to detect the green vegetation.

To a certain extent of decision, the methodology was made on the basis of availability of data, particularly the satellite images. The applied procedures are listed as follows:

I Comparative analysis on NDVI profiles for samples taken on maximum 10 days composite NDVI time series with 8 km resolution, based on NOAA (GAC) for the period of 1989 to 1993;

II Analysis of NDVI profiles derived from NOAA - AVHRR daily time series (LAC, with 1.1 km resolution) images for 1991 supplemented with meteorological data as well as recorded data on the pollution;

III Analysis of the time sequential images of Landsat TM for dates before, during and after the pollution using the following methods:

1) Visual interpretation of False colour composite (RGB 4,3,2) images

2) Pixel based image analysis(NDVI differencing) of 1990 from those of 1991.

3) Density slicing of the NDVI difference images based on thresholds obtained through visual interpretation and pattern recognition.

4) Performing statistical test on the taken samples from the NDVI images of the rangelands.

Three data sets of satellite images, including the maximum 10 days composite NDVI time series, based on NOAA (GAC, 8 km) for the period of 1989 to 1993, time series daily AVHRR images (LAC) for 1991 and time sequential Landsat TM images for dates before, during and after the pollution time were obtained. The collected image data were processed and interpreted, supplemented by other ancillary data like meteorological data in a GIS environment.

Considering the regional scale of the study and the available remotely sensed data, field observations and measurements it was concluded that a comparative study should be applied on the basis of the chosen vegetation index (NDVI).

CORRECTIONS

As a result of investigations on the use of different techniques for haze correction, it was found that the method, based on subtraction of the additive effects of the atmosphere, called the rule of thumb is accurate and reliable for bands 4, 5 and 7. However in this method careful consideration should be given to some aspects of spectral characteristics of dark objects in the scene like water bodies for the visible bands.

As miss-registration could reduce the accuracy of the results, particularly in the pixel based image analysis, the geometrically corrected images were checked for positional errors. It was found that the geometric correction with an accuracy of less than one pixel size (RMSE or Sigma being around one) is quite acceptable for this sort of studies and no effects of miss-registration can be detected on the corrected images and map outputs.

ANALYSIS AND DISCUSION

Study of the maximum 10-days NDVI images (GAC) time series for 1989-1993 and daily NOAA-AVHRR (LAC) in 1991 have proved that NDVI is an excellent index for detecting green vegetation cover globally or locally. The NDVI profiles derived for a number of sample points on the images in the study area show that NDVI values for all of the points were lower in 1991 than in 1990, 1992 and 1993 except 1989, because of less rainfall.

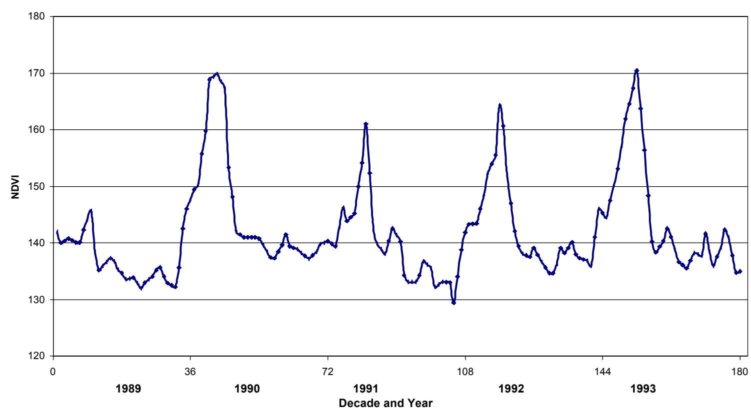


Figure 1a: Evolution of NDVI profile value at point N0 1 (plate 6.1) in 1989 to 1993, located in rangelands area with mixed forb and tree vegetation cover type

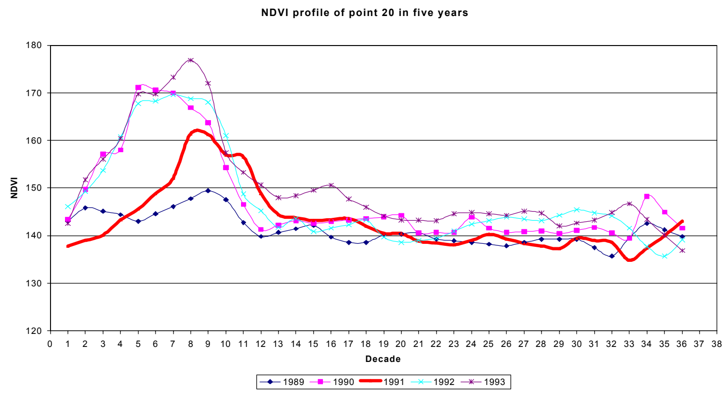


Figure 1b: Comparison of NDVI profiles in five years at point No 20(see main volume) shows extreme lowering on peak and duration of the vegetation growth in 1991 compare to the years before and after.

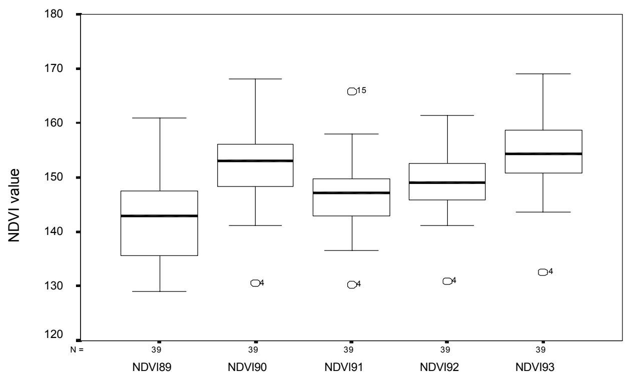
Comparing NDVI profiles for different years showed not only that the peak of the NDVI values in the growing season was lower, but also the area under the NDVI curve (total amount of green vegetation) decreased in 1991. The statistical analysis and t-test carried out on the NDVI values in different years showed that the reduction of NDVI values was significant in 1991 with more than 95% of confidence level.

as presented in table1. Moreover the box plot was used to exploratory present the statistics of the NDVI values of the taken samples for the different years.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1	NDVI90 - NDVI91	5.4149	3.2815	.5255	4.3511	6.4786	10.305	38	.000
Pair 2	NDVI91 - NDVI92	-2.5800	4.0753	.6526	-3.9011	-1.2589	-3.954	38	.000
Pair 3	NDVI91 - NDVI93	-7.8010	2.9613	.4742	-8.7610	-6.8411	-16.451	38	.000

Table 1: shows the information on statistics of paired samples as well as the significant differences on decrease on vegetation cover between 1991 and the years before and after.

Figure 3: Box plots of average NDVI values in period 1989-1993 showing the reduction on mean and median values of the NDVI data set. N= size of data, x-axis is year and Y-axis is NDVI values.



Results of study of the NOAA, 1.1km resolution based NDVI profiles supplemented with of daily rainfall and temperature records, show that the NDVI profiles were not raised in the early stages of the growing season in most of the taken sample points or they have been dropped immediately after the occurrence of black rainfall(see figure 4a,b).

Although a richer vegetation could be expected when rainwater is available for growth of plants, especially in the early stages of the growing season, the NDVI values decreased after polluted rain started to fall. Therefore, it is concluded that such distinct negative changes can be attributed to the pollution.

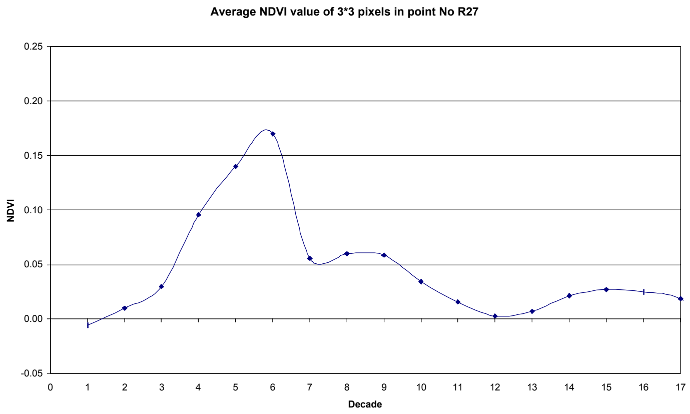


Figure 4a.. NDVI profile at point R27 (see plate 6.6 in the main volume), vegetation cover Ephemerals. Elevation of this point is 130 metre above see level.

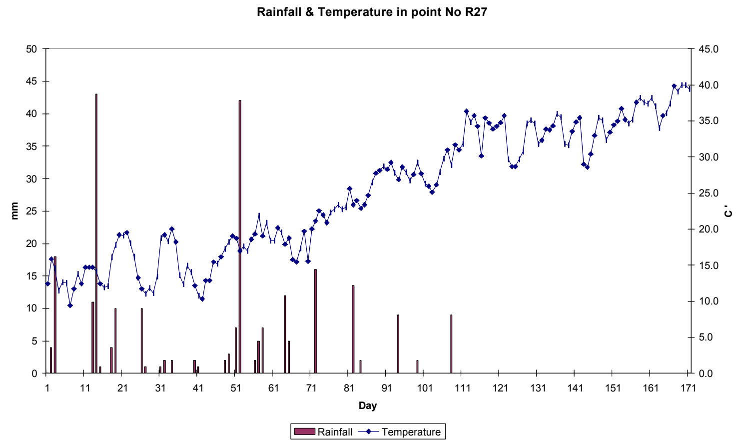


Figure. 4b: Daily rainfall and temperature in point R27(the same point as above)

Establishment of a relation between the NDVI values and the distance from the source of the pollution was proved that there was a direct relation between decrease of vegetation cover and increase on distance from the source of the pollution. This fact also is another strong proof of the impact of the pollution at different levels. (see figure 5).

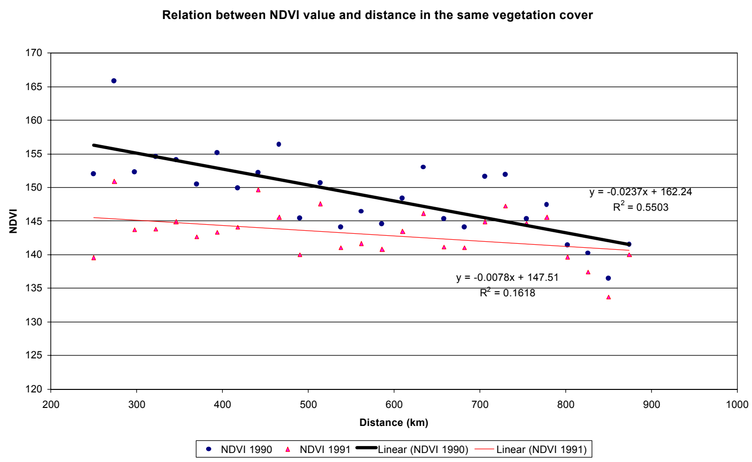
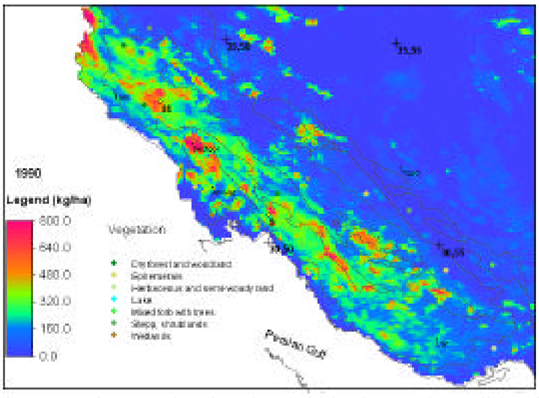


Figure 5: Relation between NDVI values and distance from source of the pollution in the uniform vegetation cover type (*annual forb with scattered trees*). Direction of the sampling path is North west to South east, along the Persian Gulf.

The produced *biomass* production maps for the years before, during and after the pollution show that vegetation cover not only was reduced significantly in 1991 as compared to 1990, but also vegetation cover had not recovered in 1992 especially in the northern parts of the study area. The situation was further worsened, because plants did not produce seed in 1991 due to the pollutants reached even to the roots of plants, so that most of them broke down before they could mature.
Estimation of the change in *biomass* in percentages in different years ndicates that the amount of biomass decreased 19 % in 1991 and 31 % in 1992 as compared to 1990 in an area of about 783976 km^2. Estimation of the change in *biomass* in an area covering the belt of 300 km wide from the Persian Gulf to the mountains and about 950 km long (see plate 2a,2b) indicates that the *biomass* decreased 22 % in 1991,and 29 % in 1992 as compared to 1990



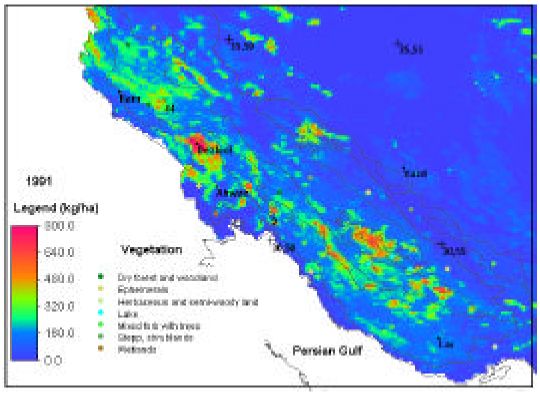


Plate 2a: The map is showing relatively good condition in biomass productivity of the rangelands in the study area in 1990. The boundaries of vegetation cover map were superimposed on the map. The coloured solid circles are indicating the cover type.
plate 2b: Biomass production map of study area in 1991, showing considerable decrease in biomass productivity. The roduced map was superimposed by the boundaries of vegetation cover map. The coloured solid circles are indicating the cover type.

Since a decrease of NDVI values in rangelands may be attributed to a drought, existence of smoke in the atmosphere, soil moisture level and probable human activities, each of those parameters was studied individually.
The meteorological study showed that there was no significant change in temperature in five years (1989-1993).
From the meteorological study it was also concluded that rainfall conditions in the year 1991 (pollution year) were significantly better (more rainfall) than in 1989 and 1990. But this condition has not been significantly changed compare to 1992. Rainfall conditions in the year 1993 were significantly better (more rainfall) compare to other studied years in the most of the synoptic stations during 1989-1993. Therefore there was favorable conditions for vegetation to grow in 1991 as compared to the reference year(1990), whereas the natural vegetation cover have been significantly decreased in 1991.

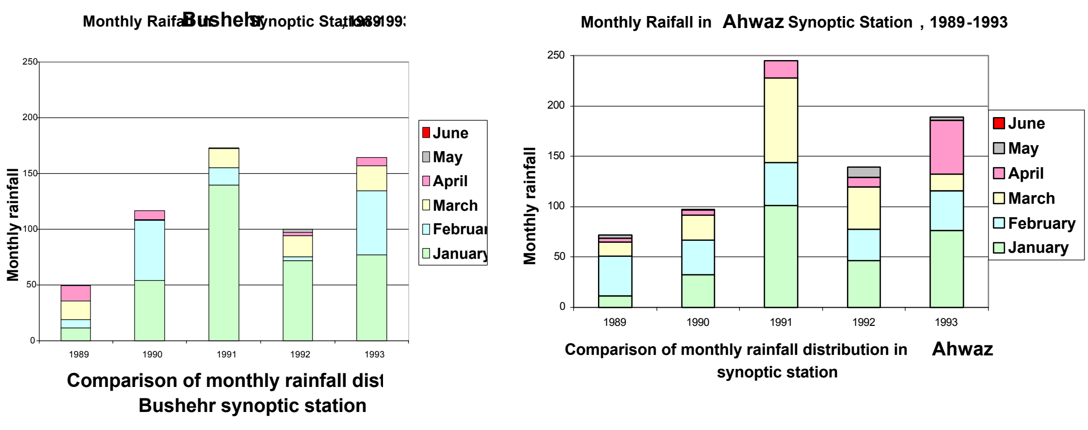
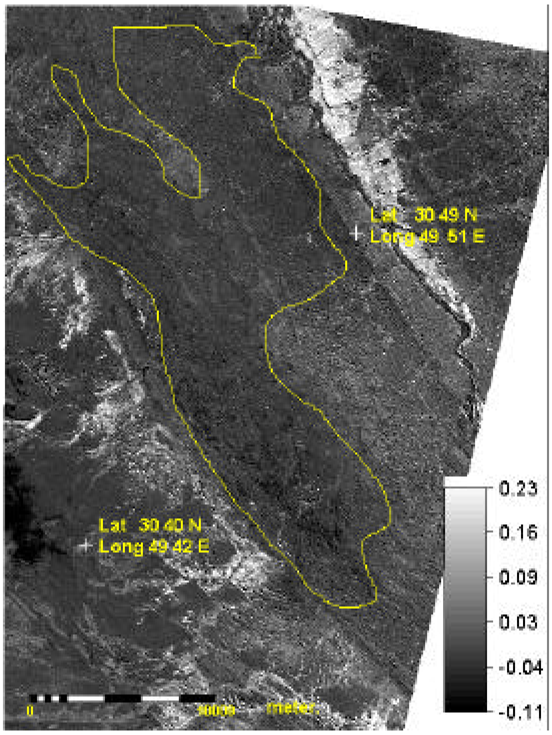


figure 6 Depth of rainfall is shown in two stations (Bushehr and Ahwaz stations) as an example, indicate much higher rainfall in 1991 compare to 1990.

An investigation of the brightness of invariant objects proved that there was no visible smoke in the atmosphere during the acquisition time of the Landsat, TM images. As these images, also originally, were cloud free and they were corrected for haze effects, so it is concluded that the decrease of NDVI values can not be attributed to the existence of smoke in the atmosphere over the study area. Study on the produced false colour composite images (*RGB band-6*) images of the years before, during and after the pollution proved that there was no change in soil moisture between those three dates. Moreover checking the rainfall data for occurrence of rainfall in the 10 days before taking the TM images led to another prove for lack of simultaneous rainfall to the dates of images. Therefore, soil moisture was not a factor for reduction of the NDVI values in 1991 in the study area. Considering the obtained results from the meteorological study and investigations on atmospheric conditions, the significant decrease in NDVI values in 1991 as compared to the reference year, is attributed surely to the impact of oil related pollutants derived from smoke plumes generated by the Kuwaiti oil well fires

Apart from the decrease in vegetation cover that was observed in 1991 as compared to the growing seasons of the years before and after, an immediate reduction in vegetation cover also was detected in the 1991 growing season, i.e. before the normal peak of growth, in some areas. For example while expecting vegetation to growth in the growing season (in March 1991), in the rangelands of e.g. Mahshahr pilot area, the vegetation cover disappeared within two weeks after receiving polluted rainfall (see plate 3a,3b)



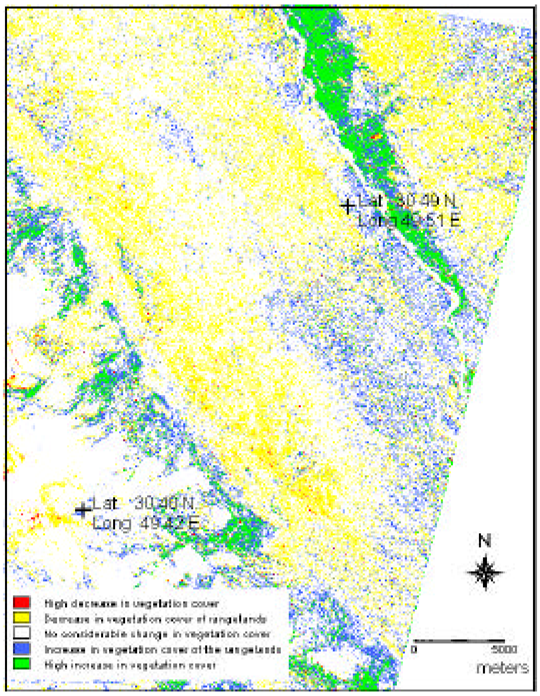
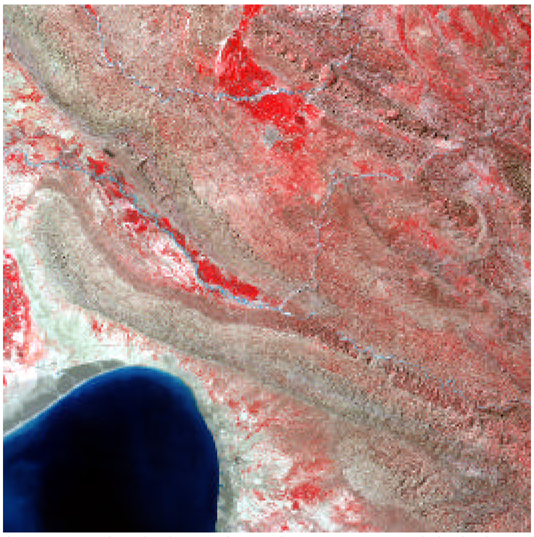


Plate 3a: NDVI values of date 27 March 1991 were subtracted from NDVI values of date 11 March in 1991. The difference image shows considerable growth on agricultural fields (light tones) and decrease on NDVI values in 27 March compare to 11 March on the rangelands (dark tones) in the area close to the Mahshahr, Southern Iran. The area that got decrease in vegetation cover (dark tones) is delineated by rough boundary of the polygon.

Plate 3b: The NDVI difference of dates of 11 March and 27 March 1991 were classified using the threshold values obtained from literature and through the analysis of TM images in this study. Mean plus and minus 0.7 standard

The decrease in NDVI values of 1991 as compared to the reference year was not caused by atmospheric conditions or topsoil moisture. The conclusion was drawn that this deterioration was attributed to the effects of the pollution or man effect like overgrazing. As the latter would rarely happen in such a vast area, this assumption is rejected also because if appeared that most of the plants started new growth in the study area, after grazing.

Visual interpretation of color composite (RGB 4,3,2) images as well as pattern recognition are quite acceptable criteria for classification of NDVI difference image, in case necessary the required field data are limited and the study area is very large (see plate4a,4b).



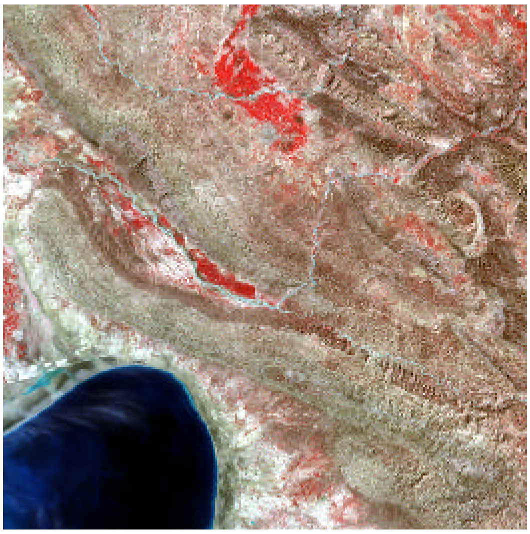


Plate 4a: Sub window of Landsat TM scene labeled 164-39 dated 25 March 1990, RGB: 4,3,2 shows existence and density of vegetation cover.

Plate 4b: .Sub window of Landsat TM scene labelled164-39 dated 12 March 1991, RGB: 4,3,2. Visual interpretation of above images indicates reduction on red tones on image 1991 compare to image of 1990 that implies high decrease on vegetation cover.

By applying these criteria and density slicing to the NDVI difference image, about 22% of the scenes were mapped as areas of significant decrease in NDVI values in 1991 as compared to the reference year. The corresponding threshold ranges for such significant negative change vary between minimum value and one mean minus 0.7 standard deviation of the NDVI difference image. This implies that one

than 26% decrease and less than 26% increase in NDVI values of 1991 as compared to the reference year (in total of 52% of changes) were assumed to be no considerable change and were classified as

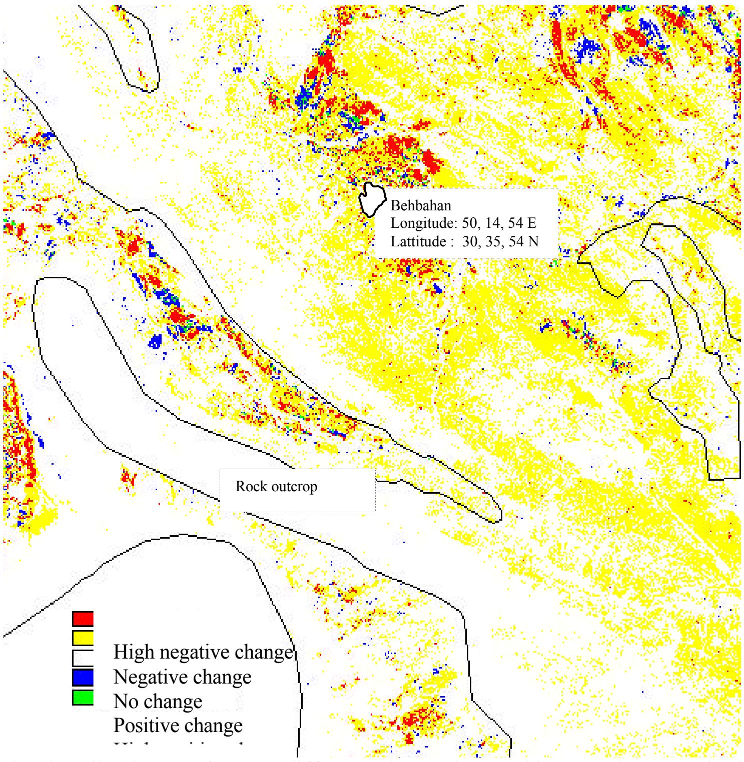


Plate 5: Improved density sliced map of NDVI difference image by masking out the water bodies and bare soils.

Since pixel based image analysis techniques are sensitive to miss-registration so by taking samples in NDVI images, significance of the changes were tested. For this purpose, the stratified random sampling was performed. In this respect more than 50 samples covering 10 by 10 pixels have been taken. The statistical t-test have been applied to the average values of selected pixels of the paired samples. The results of statistical analysis were presented by exploratory diagram and figures and tables. For detail, refer to reference No. 2.
Stratified random sampling on the produced NDVI images showed that the decrease on NDVI values or considerable decrease in vegetation cover in 1991 compare to the reference year were significant with more than 95% of confidence level.

CONCLUSION

All of the approaches, (based on available data) such as visual interpretations, image algebra and statistical analysis and tests proved that the green vegetation cover was reduced in 1991 compare to the year before. While there was much rain and there was no significant climate in the region change
As a result, it was found that integrated use of remotely sensed images with different resolutions also with support of available ground data and statistical analysis is reliable approach to detect the impact of environmental pollution on vegetation cover, particularly when the event is not accessible in term of time. This study showed that natural vegetation cover was significantly decreased in the areas which have been affected by pollution during the Persian Gulf war.

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