USE OF OPTICAL SATELLITE IMAGES FOR THE RECOGNITION OF AREAS DAMAGED BY EARTHQUAKES

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ABSTRACT

After an earthquake occurs, it is vital to identify hard-hit areas and evaluate the degree of damage. The evaluation can be carried out through a field reconnaissance survey. However, it is time consuming and requires a lot of resources. In case of a large natural disaster, a fast assessment of the damaged areas is required to dispatch rescue teams to the heavily damaged areas and draw recovery plans. In this paper, satellite images are used to identify the affected areas due to the 1999 Kocaeli, Turkey earthquake. A method is developed to recognize the heavily damaged areas, sunk areas into the sea, and the areas affected by fire. The damage detection has been carried out by comparing and rationing between different bands of the LANDSAT/TM satellite images taken before and after the earthquake. The results obtained by using this method are then compared with the ones that were obtained from field surveys.

Introduction

Information from remote sensing satellites has been used in various applications. Remote sensing satellite images include an array of information on a large area of land. Recently this technology has become a tool in damage identification after the occurrence of natural disasters like floods, landslides or earthquakes (e.g. Matsuoka and Yamazaki, 1999). The identification of damage from a large area gives vital information that authorities can use to plan rescue procedures as well as to draw a general idea of the magnitude of the damage. The location of different types of damage like fire outbreak, ground settlement and building damage using optical remote sensing data is considered in this study.

In order to identify the different kinds of damage, the comparison of optical satellite images taken before and after an earthquake is conducted. In this study the area around Gölcük, Turkey has been focused. The images that were used in this study are those taken by Landsat/TM satellite before and after the 1999 Kocaeli, Turkey earthquake.

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First, image-to-image registration was carried out to match the images, (i.e., geographic correction). To detect the fire outbreak we compared the profiles along X-axis and Y-axis of the pre- and post-event images. For the detection of the sunken area into the Sea of Marmara the histograms of the infrared band are matched and compared the result images. Finally using the Normalized Difference Vegetation Index (NDVI) new images are generated. The ratio of these images is compared with the ground truth data to obtain certain indexes that correspond to the different levels of damage.

The 1999 Kocaeli Earthquake

On August 17th, 1999 at 03:01 a.m. (local time) an earthquake of magnitude Mw=7.4 struck the North Anatolian Fault Zone with the epicenter near the Gölcük in the northwestern part of Turkey (Fig. 1). The earthquake caused tremendous damage to buildings, more than 200,000 residential units and more than 30,000 business units were lightly to heavily damaged. Due to the collapse or heavily damaged building, more than 17,000 people were killed and almost 44,000 were injured. According to the World Bank the property losses range from $3 to $6.5 billion (1.5 percent – 3.3 percent of Gross National Product). In addition the earthquake has had a huge social impact, the fatality rate from the earthquake is in the range of 14.3 per thousand depending on the affected province (World Bank, 1999).

Figure 1. The epicenter of the 1999 Kocaeli, Turkey Earthquake.

Satellite Data and Image Registration

The data used in this investigation are remote sensing images from Landsat/TM (TM stands for Thematic Mapper) taken over the affected area. The images were taken on March 27th, 1999, pre-event image, and on August 18th, 1999, post-event image, it is one day after the event. The images cover an area of 185 km x 154 km. From these raw images we have selected an area including Gölcük and Adapazari. The reason of the selection of this area is that it was heavily damaged and has different types of damages (e.g. subsidence, fire, building collapse). Other reason was to reduce the time of computation.

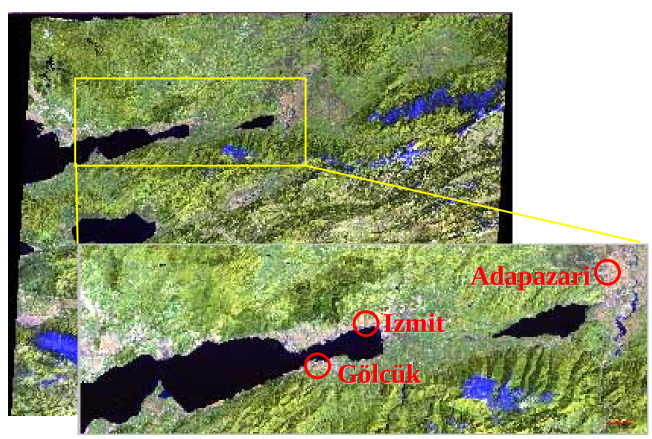


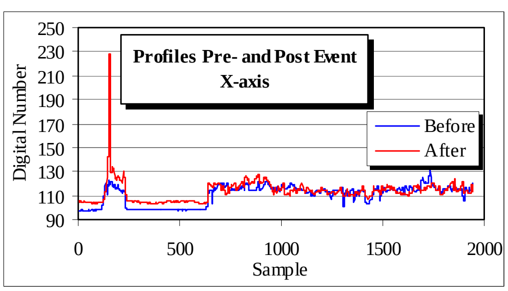
Figure 2. The raw image and the selected area of Landsat/TM.

Since the images were acquired at different dates they do not match. In order to compare a pixel-to-pixel comparison, the pixels in the pre- and post-event images should represent the same area on the earth surface. To match two or more images they have to be registered, that is they must be expressed in terms of the same coordinate system. To match two images they can be transformed so that they have the scale and projection properties of a map this is called *geometric correction*. But it needs a geographically correct map and each image has to be corrected separately. A related technique, to match two remote sensed images, called *registration*, is the fitting of the coordinates of one image to that of a second image of the same area. To make an image-to-image registration one of them is chosen as a master to which the other, known as the slave, is to be registered. In this study the master image is the pre-event image to which the post-event image, is registered. The image registration was made using the raw images, and in the area of 185km x 154km, 250 ground control points were defined. As ground control points well-defined shapes were selected, like road intersections, border of dams, distinctive water bodies, rivers, etc. Finally, rotation scaling and translation method was used for warping the slave image and the nearest-neighbor method was used for resampling.

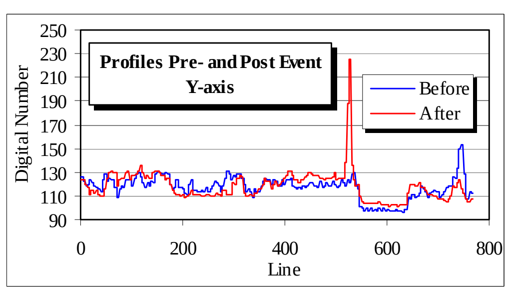
Area Damage by Fire

The Tüpras refinery, located in Körfez, suffered a very large damaged due to the fire ignited in the naphtha tank after the shake and spread into the tank farm by combustible spill (Johnson, G., et. al., 2000). The fire as well as the heat caused damage to numerous tanks and due to breaks in the pipelines, the refinery lost fire-fighting capability and it took several days to have the fire under control. To identify the areas affected by fire through remote sensing data we compare the profiles of the pre- and post-event images. The profile represents the distribution of the digital number (DN) of certain band along a strip of the image (DN represents the level of reflectance of certain ground area). This strip can be taken over the X-axis or Y-axis. For this comparison the band 6 (far infrared band) is used. Before making the comparison correction for seasonal effect is made. This correction was made by subtracting the average difference between the digital numbers of the images (pre- and post-event) from the values of the digital number of the post-event image.

We can see in the Fig. 3 that there is a pattern in the profile before the earthquake as well as in the after one. But in the region between sample 100 and sample 200, in the X-axis, and between the line 500 and 600, in the Y-axis (this section corresponds to the refinery), there is a peak value in the post-event profile that identifies the high temperature due to the fire outbreak at the refinery. The flat pattern sections in this graph represent the area of the sea. And the almost common section belongs to the ground surface. Composite RGB images are shown in the Fig. 4.

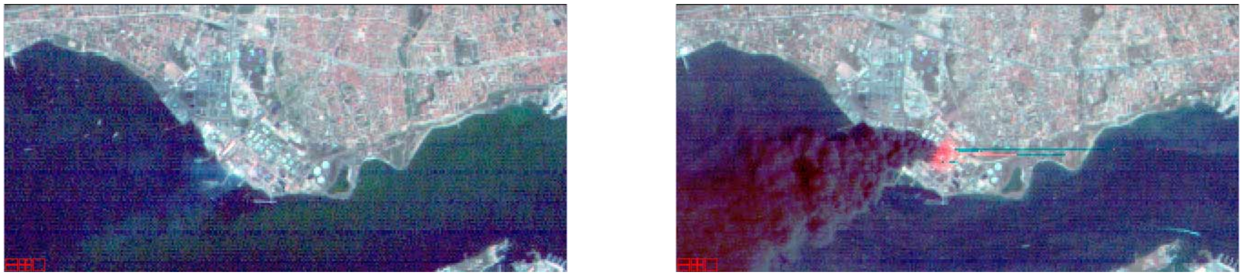


(a)



(b)

Figure 3. Profiles of the pre- and post-event images of the band 6. (a) Profile along the X-axis. (b) Profile along the Y-axis. Notice the peak value that represent the area around Tüpras refinery.



(a) (b)

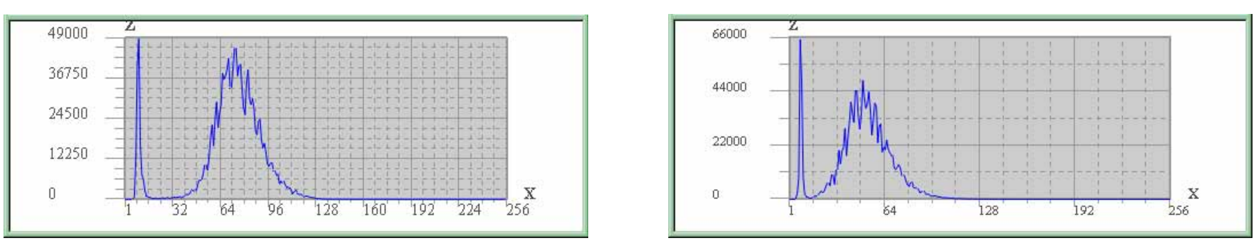
Figure 4. Remote sensing images (RGB 721) around Tüpras Refinery. (a) and (b) Images before and after the earthquake respectively. In (b) notice the fume coming up from the refinery and the fire.

Subsidence

A huge scale ground subsidence occurred at Gölcük (Fig. 4). The ground subsidence took as a result of normal faulting associated with the main lateral strike slip event (Aydan, et. al., 1999). The fault-bounded tectonic subsidence caused 4 km long section of the coast near Gölcük to submerge about 2 to 3m, with considerable flooding of buildings and loss of lives by drowning.

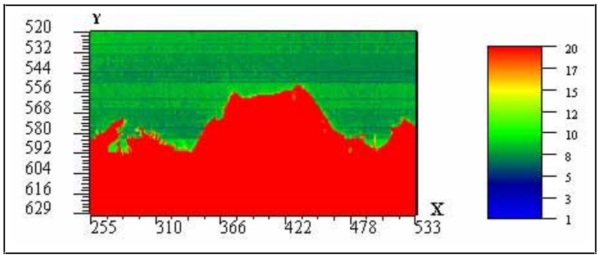
Figure 4. Subsidence in Gölcük.

The characteristic spectral reflectance curve for water bodies shows a general reduction in reflectance with increasing wavelength, so that in the near infrared the reflectance of deep, clear water is virtually zero. To detect those areas sunk into the Sea of Marmara we have used the near infrared band (band 4). The histograms of the images are matched so that we obtain an apparent distribution of the brightness values in certain range, and as a result we obtain two images in which the differences of water bodies are highlighted. The histograms of the pre- and post-event images that correspond to the near infrared band of the region of interest (see Fig. 2) are shown in the Fig. 5. In these graphs it can be seen that the histogram has two sectors, which the left part represents the distribution of the water's reflectance. Since the reflectance value of the water in the near infrared band is low, we match the histograms in the range 1 to 20 and obtain the images in the Fig. 6. Comparing these two images, it can be seen that in the image of the post-event (Fig. 6 (b)) there are some areas that differ from those in the pre-event image. These differences represent the inundated area.

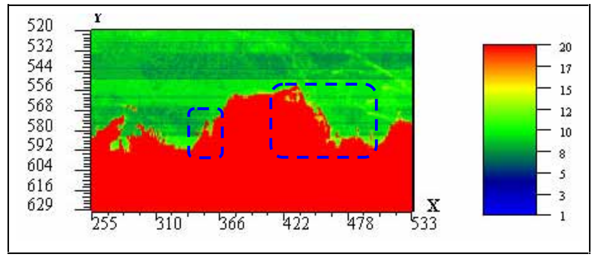


(a) (b)

Figure 5. Histogram of the near infrared band, (a) pre-event, (b) post-event.



(a) Pre-event image.



(b) Post-event image.

Figure 6. After matching the histograms the difference in the sunken area is highlighted.

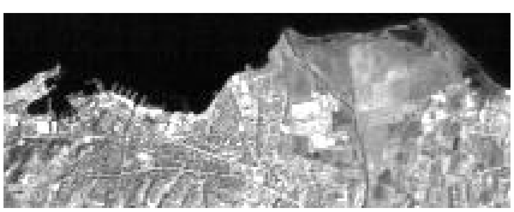
Building Damage

Figure 7. Building collapse in Gölcük.

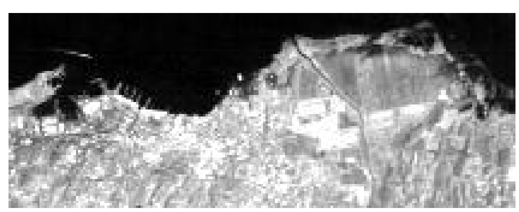
Ratios between images are effective in enhancing or reveling information when there is an inverse relationship between two spectral responses to the same physical phenomena (Campbell, 1996). If two spectral responses have the same spectral behavior, the ratio provides little additional information. But if they have quite different spectral responses, the ratio between two values provides a single value that concisely expresses the contrast between the reflectance from two images. In this study two kind of ratios have been studied, the Infrared/Red ratio and the Normalized Difference Vegetation Index (NDVI). The second index gave better results that are presented in this study. The NDVI is defined as follows:

$$NDVI = \frac{IR - R}{IR + R}$$

Since our data comes from Landsat/TM satellite the IR and R bands correspond to band 4 and band 3 respectively. As a result of the arithmetic operations we have obtained two enhanced images (Fig. 8) that correspond to images before and after the earthquake.



(a)



(b)

Figure 8. Images obtained through NDVI. (a) And (b) pre- and post-event image respectively.

In the center of the image (b) of Fig. 8 a bright area can be distinguished that highly differs from that one in the pre-event image. Within this area there are damaged buildings at different levels, from slightly damage to total collapse. The brightness in this area is due to the spread of debris after the building collapse.

Comparison with Ground Truth Data in Gölcük

After the earthquake occurred some reconnaissance surveys were conducted. A GIS map, shown in the Fig. 9, presents the different levels of damage as a result of the field survey conducted by the Architectural Institute of Japan. The ratio of the images, obtained by the NDVI, is compared with the ground truth data, for the different levels of damage. To compute the ratio we consider the mean value of the digital numbers that correspond to a region of certain level of damage (AIJ, 1999).

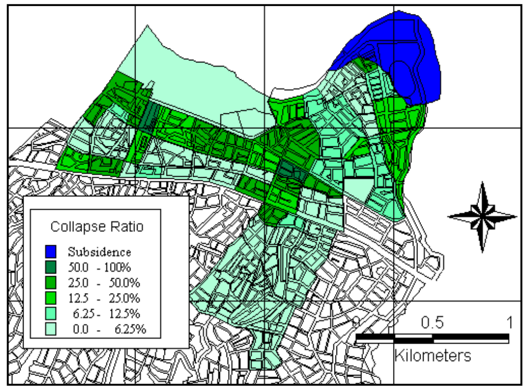


Figure 9. Distribution of the damage in Gölcük (AIJ, 1999).

This ratio, shown in the Fig. 10, presents a trend from higher values to lowers ones, it means from high to lower reflectance, except for the sunken zones, where the ratio is out of this trend.

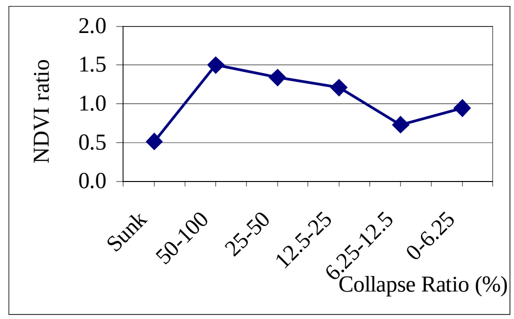


Figure 10. Ratio of the NDVI After/Before.

Conclusions

Landsat images before and after the 1999 Kocaeli Earthquake were investigated. The analyzed region of interest showed different types of damage (i.e. fire, subsidence and various levels of building damage). The analysis of the near infrared band (band 4 in case of Landsat/TM 5 satellite) gives a good approach to detect the flooding. The ratio of the NDVI of the images before and after the earthquake gives some trend that conveys some relationship between the different levels of damage. Although the results are in good agreement with the field survey, there is still a high variability in these indexes and further study using other bands and data from other areas is recommended.

References

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