DISPLAYING EARTHQUAKE DAMAGE AN URBAN AREA USING A VEGETATION-IMPERVIOUS-SOIL MODEL AND REMOTELY SENSED DATA

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ABSTRACT:

The aim of this study was to use remotely sensed data to record earthquake-induced land cover change. On 17 August 1999, an earthquake struck northwestern Turkey, at 3:01:17 a.m. local time and lasted about 40 seconds. The most heavily damaged area was around the Gulf of Izmit and the city of Adapazari. The towns of Golcuk and Yalova, along the southern shore of the Gulf, the harbour city of Izmit at the eastern end of the Gulf, the town of Sapanca about 40 km east of Izmit and the city of Adapazari 50 km east of Izmit were sites of massive structural damage and extensive ground failure. The pre-earthquake and post-earthquake SPOT HRV images of the city of Adapazari were geometrically corrected and classified and revealed that 7.1 % of the post-earthquake area comprised collapsed buildings. The trend and relative magnitude of earthquake-induced land cover change were displayed using the Vegetation, Impervious, Soil (V-I-S) model.

1. INTRODUCTION

The North Anatolian Fault Zone (NAFZ) is one of the most important active strike-slip faults in the world and the most important active fault in Turkey. During the last century, many catastrophic earthquakes occurred on or around this fault, resulting in the collapse of approximately 450 000 buildings and the death of over 80 000 people. Last century 25 catastrophic earthquakes (moment magnitude, Mw > 6.5) occurred and seven originated in northwestern Turkey (Barka and Nalbant, 1998). For example, between 1939 and 1967, six large fault ruptures formed a westward-migrating sequence of events along a 900-km long near-continuous portion of the NAFZ (Barka, 1996) and most of the earthquakes in the Marmara Sea region occurred on the northern strand of the NAFZ (Ambraseys and Finkel, 1991; Barka, 1991; Barka, 1992).

The 17 August 1999 Kocaeli (Izmit) earthquake (Mw 7.4) occurred on the NAFZ in the northwestern part of Turkey and caused heavy damage in this density populated and industrialized region. Cities particularly affected were Kocaeli, Adapazari, Yalova, Golcuk, Istanbul, Bolu, Bursa and Eskisehir and these were all on or within 10 km of the NAFZ. The earthquake's epicentre was located at latitude 41.8º and longitude 29.9º (near Golcuk) at a depth of around 10 to 16 km. The most heavily damaged area was around the Gulf of Izmit and the city of Adapazari. The dead and injured totalled approximately 15,851 and 43,953 respectively in city centres (Sahin and Tari, 2000) and approximately 18,000 and 48,000 respectively in greater urban areas (Barka, 1999). The distribution of those who died in city centres was: Golcuk (5,025), Izmit (also known as Kocaeli) (4,093), Adapazari (also known as Sakarya) (2,629), Yalova (2,502), Istanbul (981), Bolu (264), Bursa (268), Eskisehir (86), Zonguldak (3) (Sahin and Tari, 2000). By way of illustration, Adapazari was 50 km from the earthquake epicenter and 3,891 people died in its greater urban area (www.sakarya.gov.tr, 2003).

Remotely sensed data have been used to record land cover change in general (Welch and Ehlers, 1987; Pathan et al., 1993; Kaya, 1996; Foody and Boyd, 1999; Yang, 2002, Kaya and Curran, 2003) and earthquake-induced land cover change in particular (Yonezawa and Takeuchi, 2001, Turker and San, 2003). The aims of this study were (i) to use SPOT HRV XI data to quantify the extent of building collapse, in the Adapazari region, as a result of the 17 August 1999 earthquake and (ii) present the land cover change trend in the study area by means of the Vegetation- Impervious- Soil (V-I-S) model.

2. METHODOLOGY

2.1 The Study Area on 17 August 1999

The earthquake started in the west, lasted for 12 seconds, paused for approximately 18 seconds and was followed by rupture in the east for 7 seconds (Barka, 1999). The maximum offset along the surface break was measured near Arifiye, east of Sapanca (between Arifiye and Adapazari) (figure 1). The fault displaced a road horizontally by about 5 m and a railway horizontally by about 2.7 m and also vertically by about 1 m.

Adapazari suffered more damage as a result of building collapse than Izmit and Yalova (figure 2, table 1), as more of buildings were constructed on readily-liquefied sediments (Scawthorn, 1999; (Erken, 1999). During the earthquake, two buildings on pile foundations and 1-2 story buildings were largely unaffected but 3-6 story buildings, typically on shallow mat foundations, displayed a substantial amount of base settlement, rotation and

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collapse (Anderson et al., 2000; Bakir et al., 2000). Other causes of building damage were due to poor building control (http://www.koeri.boun.edu.tr/ depremmuh/ extent.htm , 2003), for example:

1. Poor concrete quality;
2. Poor reinforcement;
3. Weak storey within a multi-storey building (e.g. open space at the first floor);
4. Structurally unsuitable alterations (e.g. added floor);
5. Long cantilevers with a heavy load;
6. Improper (unstable, corrupt, illegal) construction.

Illegal upward extensions that exceed the competence of the foundations (point 4 above) were a common feature of collapsed buildings. This poor building control was an indirect consequence of the recent rapid increase in population (8.8 %, 1990-1997 within the inner city boundary) (table 2). However, that pressure is no longer present, as between 1997 and 2000 (before and after the earthquake) the population decreased by 6.5 % within the inner city boundary.

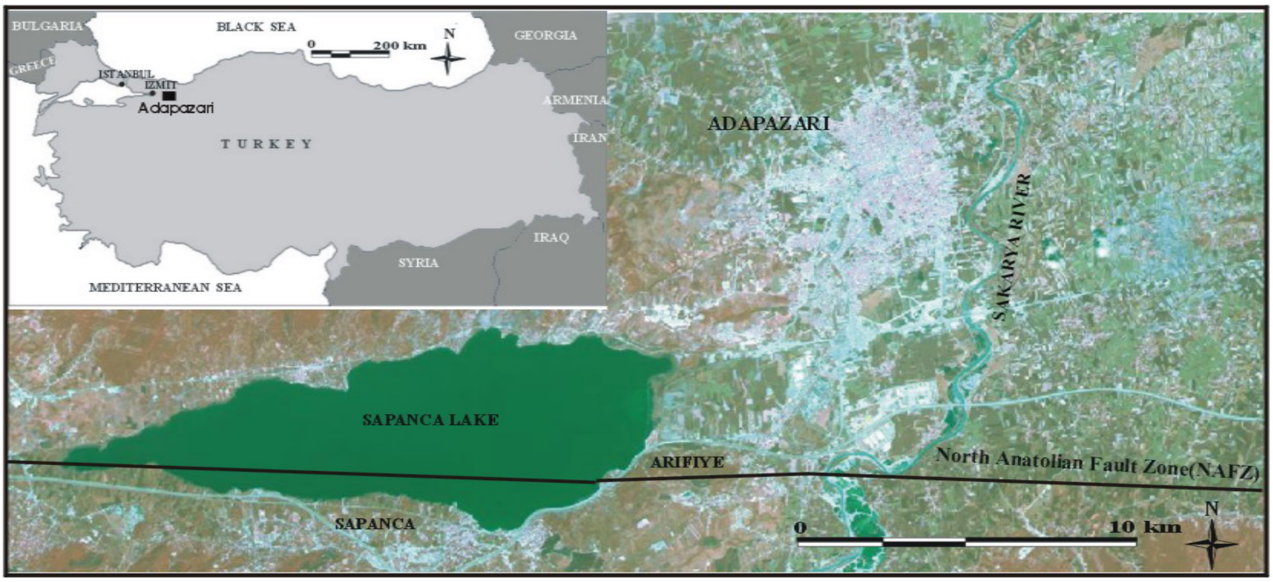

Figure 1. Study Area.

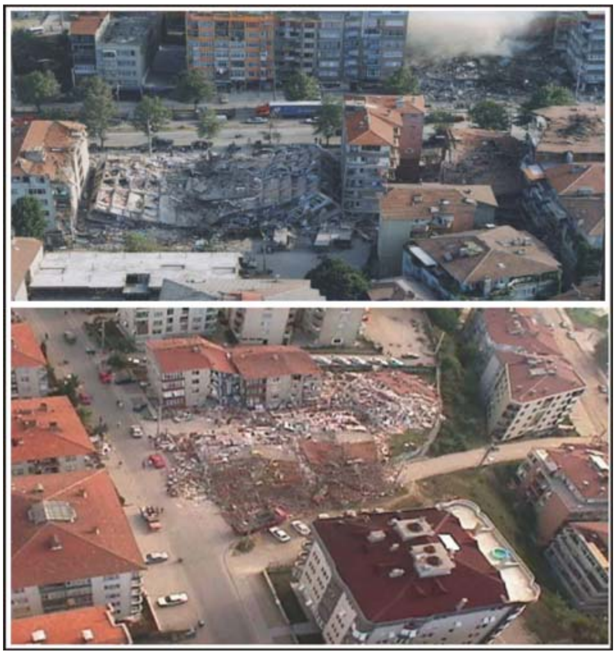

Figure 2. Ground photographs of 1999 earthquake damage.

City	Heavy damage to collapse	Medium damage	Light damage
Adapazari	11 373	5 815	8 763
Izmit(Kocaeli)	3 614	12 944	13 335
Yalova	9 637	8 988	12 677

Table 1. Number of buildings damaged in Adapazari, Izmit and Yalova by the 1999 earthquake (http://www. koeri.boun. edu.tr/ depremmuh/extent.htm, 2003).

Population	1990	1997	2000
Within the greater urban area	272 039	354 029	340 825
Within the inner city boundary	169 099	184 013	172 000

Table 2. Population of Adapazari within both the greater urban area and the inner city (http://www.die.gov.tr/nufus_sayimi/, 2003).

2.2 Image classification and V-I-S Model

SPOT HRV XI images for 25 July 1999 and 4 October 1999 (spatial resolution of around 20 metres), were geometrically corrected using 26 ground control points derived from a 1:25,000 map of the area. Images were transformed to Universal Transverse Mercator (UTM) coordinates using a first order polynomial transformation and nearest neighbour resampling. The pre-earthquake and post-earthquake images were classified using the Iterative Self-Organizing DATA (ISODATA) classifier (without atmospheric correction). Twenty-five ISODATA spectral classes were combined to form 4 classes: (i) vegetation, (ii) impervious I (urban), (iii) impervious II (urban and collapsed buildings) and (iv) soil (neither vegetation or urban).

The Vegetation-Impervious-Soil (V-I-S) of Ridd (1995) (figure 3) describes the biophysical composition of an urban area as a function of three components: vegetation, impervious (surfaces such as buildings and roads) and soil (defined as surfaces that are neither vegetation or urban) (Madhavan et al., 2001; Phinn et al., 2002). As such it provides a means of assessing the trend and relative magnitude of land cover change in an urban area.

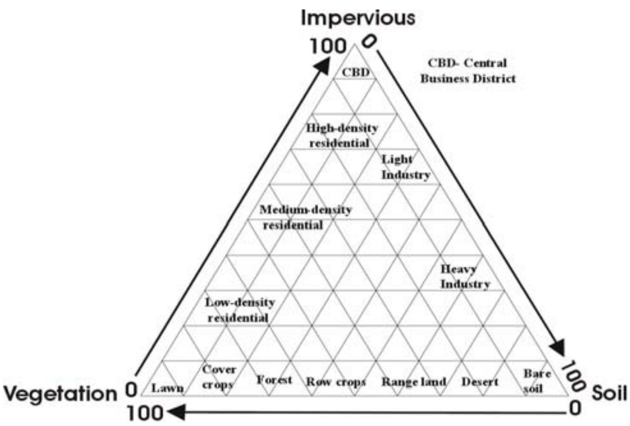

Figure 3. The Vegetation-Impervious-Soil model (Ridd, 1995).

3. RESULTS AND CONCLUSION

The inner city of Adapazari comprised 25.1 % vegetated, 33.7 % impervious and 41.2 % soil before the earthquake but 23.5 % vegetated, 32.7 % impervious (7.1 % were collapsed buildings) and 43.8 % soil after the earthquake (figures 4, 5). The area of collapsed buildings contained less shadow and more bright (concrete) surfaces than the other impervious areas and was distinguished readily by the classifier.

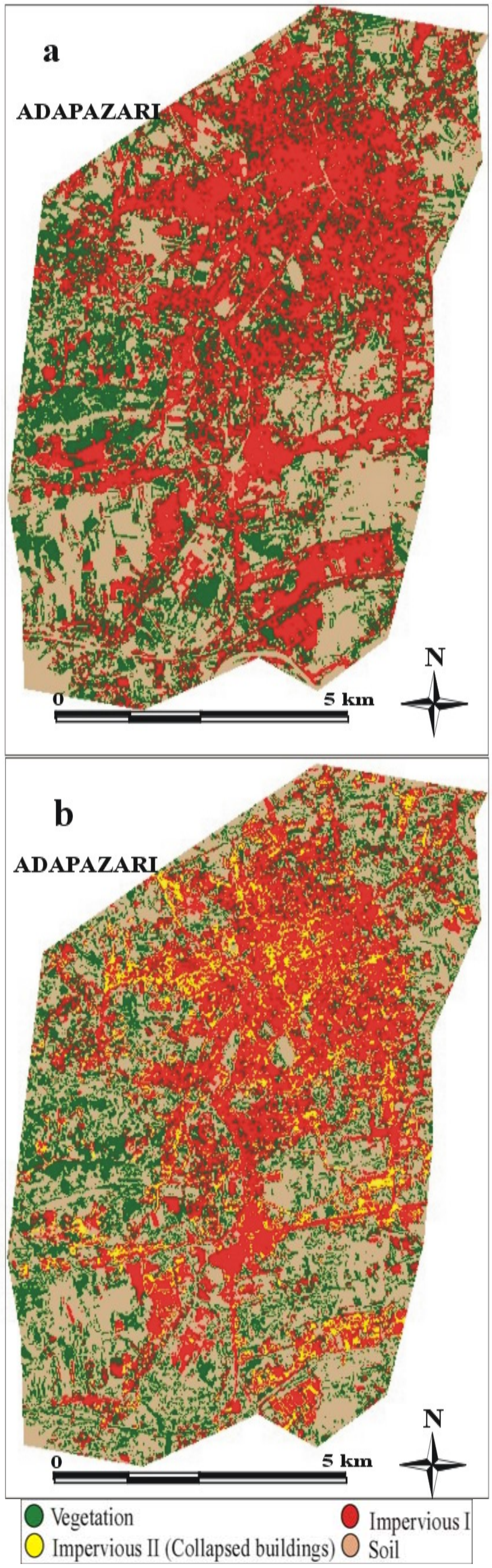

Figure 4. Four class images of Adapazari a) pre-earthquake and b) post-earthquake.

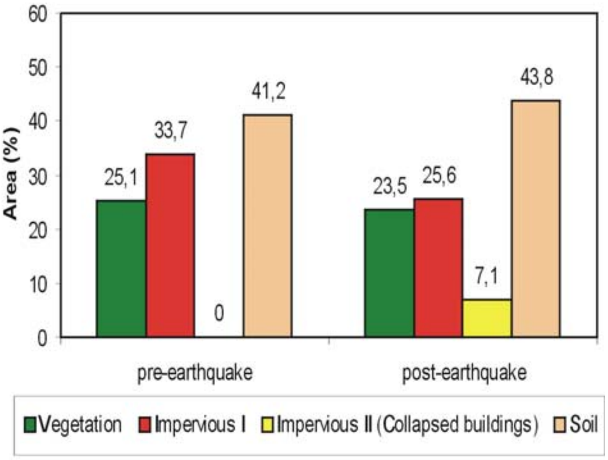

Figure 5. Land cover of Adapazari before and after the earthquake

The area of vegetation, impervious and soil remained essentially unchanged after the earthquake but the impervious class comprised two very different components: collapsed buildings and other impervious surfaces. To display this change using the V-I-S model the collapsed building class was added to the soil class, as it was no longer functionally urban (figure 6). The land cover change vector indicates in a standardised way the direction and the magnitude of land cover change that has occurred.

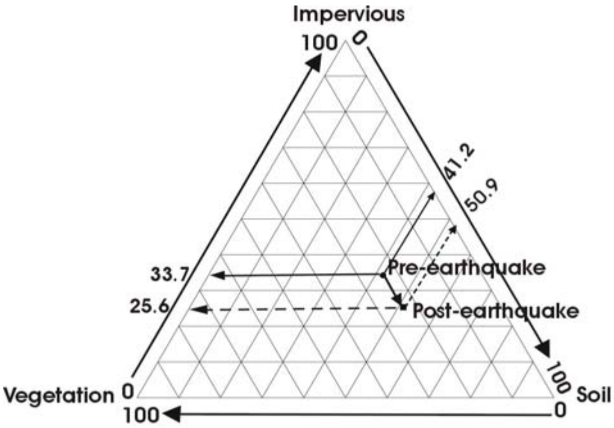

Figure 6. Trend of Vegetation-Impervious-Soil model from pre-earthquake to post-earthquake.

The Kocaeli (Izmit) earthquake caused catastrophic and dramatic changes in the land cover of Adapazari. In this study, using classification of pre-earthquake and post-earthquake SPOT HRV images, collapsed building areas were identified. The land cover change direction vector was determined by means of the V-I-S model using data from the classified images. It was concluded that SPOT HRV XI data and the V-I-S model could be used to provide a standardised means of representing earthquake-induced land cover change in an urban area

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