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Remote Sensing Applications
P. S. Roy
R. S. Dwivedi
D. Vijayan
इसरो isro
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Remote Sensing Applications
National Remote Sensing Centre

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Earthquake and Active Faults

15.1. Introduction

Natural hazards and catastrophes are recurring phenomena which affect one or the other part of the world every now and then. Among all such hazards, the most devastating are the earthquakes with intensity over 5 on Richter scale. This is because occurrences of earthquakes are quite uncertain. An earthquake is the result of a sudden release of energy in the Earth's crust that creates seismic waves. The earthquakes are, generally, recorded with a seismometer, also known as a seismograph. The moment magnitude of an earthquake is conventionally reported and this data speaks about the intensity of earthquake. It is seen that magnitude 3 or lower earthquakes are, generally, imperceptible and the earthquakes with magnitude 7 cause serious damage over large areas. Intensity of tremor is measured on the modified Mercalli scale. Tectonic earthquakes occur anywhere within the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane. In the case of transform or convergent type plate boundaries, which form the largest fault surfaces on earth, plates will move past each other smoothly and seismically only if there are no irregularities or asperities along the boundary that increase the frictional resistance.

Most boundaries do have such asperities and this leads to a form of stick-slip behaviour. Once the boundary has locked, continued relative motion between the plates leads to increasing stress and therefore, stored strain energy in the volume of the rock around the fault surface. This continues until the stress has risen sufficiently to break through the asperity, suddenly allowing sliding over the locked portion of the fault, releasing the stored energy. This energy is released as a combination of radiated elastic strain seismic waves, frictional heating of the fault surface, and cracking of the rock, thus causing an earthquake. This process of gradual build-up of strain and stress punctuated by occasional sudden earthquake failure is referred to as the Elastic-rebound theory. It is estimated that only 10 percent or less of an earthquake's total energy is radiated as seismic energy. Most of the earthquake's energy is used to power the earthquake fracture growth or is converted into heat generated by friction. Therefore, earthquakes lower the Earth's available elastic potential energy and raise its temperature.

Although researchers relentlessly work on earthquake prediction; operationally earthquake is difficult to predict or forecast. Remote sensing based studies are being attempted to detect thermal anomaly associated with earthquake to demonstrate its potentials in earthquake-related studies. Moreover, remote sensing-based study also attempts to relate ionosphere disturbances associated with earthquake to use it as a tool for prediction. A specialized technique called DinSAR (Differential Interferometric Synthetic Aperture Radar) technique is used to record the dynamic movement in parts of earth with the help of spaceborne SAR (Synthetic Aperture Radar). Moreover, the delineation of active faults with help of active fault-related morphometric and geomorphic signature using satellite images helps in long term prediction of earthquake.

Generally, intensity and magnitude of earthquake is known only after the earthquake has actually occurred in a region and causes immense destruction and loss of life and property. This requires all time preparedness for the authorities and the people. The use of satellite imagery and remote sensing techniques also play a vital role in the post earthquake management in the short run as well as in the long run. Availability of high resolution satellite data with short revisit offers immense potential in post earthquake disaster management related studies. Moreover, satellite data helps in creating information for seismic hazard zonation. The integrated analysis of geologic and seismologic data, field observations, lineament data, derived from satellite radar images if integrated with historical data on earthquake, demographic data, soil type, soil deformation analysis etc., data would help to generate seismic hazard zonation map of an area. These maps would evaluate the potential of occurrences of earthquake in an area so that proper pre-earthquake management/engineering practices can be chalked out.

15.2. Global, National Issues and Scneario Development

Although no proper methods are proved as suitable for earthquake prediction with approximate idea of the magnitude of the earthquake. Remote sensing-based study used to detect the thermal anomaly associated with earthquake. But no earthquake has been predicted based on remote sensing based study. Remote sensing-based study also proved useful in detecting active faults; which believed to have activated in recent geological past (<10,000 years) and therefore these zones are very useful for establishing the seismic stations to monitor the deformations or any future earthquake. In India, in the recent past several active faults have been identified using remote sensing based study in the lower Himalayas.

Seismic hazard zonation is another approach that helps minimizing the devastative impact of earthquake. Seismic hazard assessment requires knowledge not only of the earthquake sources and propagation of seismic waves, but also of the effect of local geology on earthquake ground shaking. However, the lack of empirical data and efficient earthquake microzonation tools have precluded a general integration of local site effects into earthquake hazard assessment schemes. Therefore, simple and fast methods for first-order site classification and methods based on rapid surveys of seismic noise in conjunction with shallow geophysical investigations are being developed. Besides advanced methods of seismic noise analysis suitable for near-surface investigations are being developed and tested. Furthermore, we examine the applicability of remote sensing techniques with the aim of mapping the topography gradient as a proxy. Investigating the role of "soil-city" interaction for local ground shaking and assessing the effect of ground motion duration on earthquake damage are additional challenging issues that have found no or only inadequate consideration in previous microzonation studies. Studies related to adequate magnitude determination, wave propagation, and ground motion prediction equations are to be incorporated, in the earthquake microzonatioin studies.

15.3. Conventional and Scientific Methods in practice

Remote sensing has been used for earthquake research from 70s, with the availability of satellite images. Initially it began with the structural geological and geomorphological studies. Active faults and structures were mapped on the basis of satellite images (Trifonov, 1984). The active faults and structures thus delineated do not form the sound base for time series analysis. Hence, there is no possibility to measure short-term processes before and after the earthquake. The current scenario of remote sensing applications for earthquake studies indicates a few phenomena related to earthquakes: These are earth's deformation, surface temperature and humidity, air humidity, gas and aerosol content. Both horizontal and vertical deformations scaled about tens of centimeters and meters after the shock. Such deformations; specially vertical deformations are recorded by interferometric SAR (DInSAR) technique with confidence. Pre-earthquake deformations are rather small – in term of centimeters. A few cases of deformation mapping after the shock using satellite data are known. Future development lays in precision SAR systems with medium spatial resolution and in combination with GPS technique. There are numerous observations of surface and near-surface temperature growth of the order of 3–5 degree centigrade prior to earthquakes. Methods of earthquake predictions have been developed using thermal IR survey. Well-known cases of gas and aerosol content change also have been observed before the earthquake. Satellite methods allow us to restore the concentrations of gases in the atmosphere: O_3, CH_4, CO_2, CO, H_2S, SO_2, HCl and aerosol. However the spatial resolution and sensitivity of currently available spaceborn sensors is not adequate for the estimation of the concentration of atmospheric gases. First promising results were obtained only for ozone, aerosol and air humidity.

Another important element of the study related to earthquake is active fault/ active tectonic related studies. In the geological sciences, tectonic refers to the processes, structures and landforms associated with the process of deformation of earth crust. In a broader sense it refers to the evolution of these structures and landforms over time. The time scale of tectonics depends on the spatial scale at which the process acts. For example, it takes billion of years for continents to develop; hundreds of million years for large ocean basin, whereas a fault scarp may be produced almost instantaneously during the earthquake (Kellar, 1997). The term active tectonic refers to those tectonic processes that produce deformation in the earth crust on a time scale of significance of human society. But the time frame required for studying these process needs to be longer- at least few hundred years to few thousand years –because earthquake on particular faults may have longer return period. One indirect way to study the tectonic process is to analyze the geological record of quaternary period to find out information indicative of deformation (e.g., presence of sand dykes within the column of particular quaternary unit such as cross bedded sandstone). Landform also bears the information on tectonic processes operated in recent geological past. Geomorphic tools used for such study are the set of landforms and quaternary deposits present at an area generally encompasses the last few thousand to two million thousand years (Kellar, 1997). Active fault or a neotectonic fault causes formation of variety of landform features including fault scarps, warped and tilted ground, subsidence features such as sag ponds and offset features such as stream channels. Each major category of faulting- strike-slip, normal, reverse – may be discussed in terms of a characteristic assemblage of landforms. There is fair amount of over lap between these different assemblages because many faults have oblique displacement, partially strike slip and partially vertical. The study of these features can provide valuable information regarding tectonic processes operated in recent geological past. Remote sensing data plays an important role in delineating such active fault signatures specially high resolution data plays significant role in delineating delicate signatures such as sag ponds; pressure ridge, benches, etc. DEM generated from stereo pair of spaceborne SAR sensors/ aerial photographs facilitates deriving geomorphic indices indicative of neotectonic signatures. Some of the critical geomorphic signatures (figure 15.1) associated with active fault/ neotectonic terrain is discussed below:

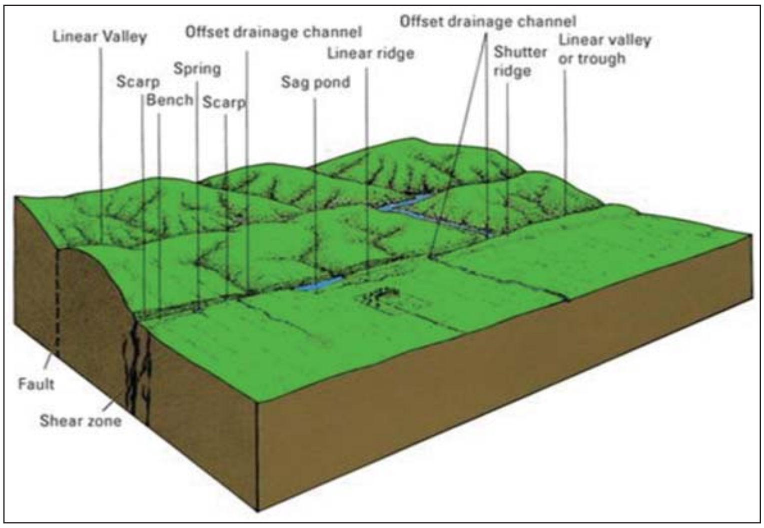

Figure 15.1: Geomorphic Signatures

- Landform analysis around active fault area is a significant exercise; which would help in delineating the trend of active fault. Some of the Landforms are very characteristic and associated with active fault
- Some faults, called creeping faults, move very slowly all the time. Structures such as bridges, sidewalks, and buildings on top of these faults will be offset by a small amount each year as the faults move. One can try to find a creeping fault by looking for bent or offset curbs and sidewalks
- Most faults don't creep, however, so geologists look for other ways that faults affect the landscape. Usually these evidences are easiest to spot from the air. For example, natural features such as streams, valleys, and ridges may have offset where they cross faults as movement from many earthquakes is accumulated. Active faults also create their own landscape features. For example, if one side of a fault moves up or down, a straight, low ridge called a scarp is created. As faults accumulate offset, the rock along the fault is broken and ground down, and the resulting shattered zone is more easily eroded than the surrounding rock. This type of erosion produces many common fault-related landforms, such as benches, saddles, and linear valleys along the fault. Faults also can disrupt the movement of underground water, forcing it to the surface to form springs and ponds. Finally, faults can be recognized by the offset they produce in the rocks that underlie the landscape, which can be recognized by careful study
- Important landforms associated with active faults (figure 15.1) are:
  - Shutter Ridge: A shutter ridge is a ridge which has moved along a fault line, blocking or diverting drainage. Typically, a shutter ridge creates a valley corresponding to the alignment of the fault that produces it
  - Fault Scarp: Fault scarp is the topographic expression of faulting due to the displacement of the land surface by movement along the fault. It can be caused by differential erosion along an old inactive fault (a sort of old rupture) with hard & weak rock, or by an active geologic fault. In many cases, bluffs form from the up thrown block and can be very steep. The height of the scarp formation is equal to the vertical displacement along the fault. Active scarps are usually formed by tectonics, e.g. when an earthquake changes the elevation of the ground, and can be caused by any type of fault, including strike-slip faults, whose motion is primarily horizontal. This movement is usually episodic, with the height of the bluffs being the result of multiple movements over time. Displacement of around 5 to 10 meters per tectonic event is common. Due to the dramatic uplift along the fault, the fault scarp is very prone to erosion, especially if the material being uplifted consists of unconsolidated sediment. Weathering, mass wasting and water runoff can soon wear down these bluffs. Fault scarps may be only a few centimeters or many meters high. Fault-line scarps are coincident with faults, but are most typically formed by the erosion of weaker rocks that have been brought alongside more resistant ones by the fault's movements. In the case of old eroded fault scarps, active erosion may have moved the physical cliff back away from the actual fault location which may be buried beneath a talus (fan) or the valley fill
  - Sag ponds: A sag pond is a body of water, which forms as water collects in the lowest parts of the depression that forms between two strands of an active strike-slip fault. The relative motion of the two faults strands results in a stretching of the land between them, causing the land between them to sink

– Beheaded Streams: Portion of a channel downstream from a fault, which is separated from its headwaters by strike-slip movement along the fault. In the process of abandoning the older downstream portion of the channel (and thereby "beheading" the downstream portion of the channel), the headwaters carve a new path straight across the fault. In subsequent earthquakes, the new channel will be offset, and it will eventually become beheaded as well. Thus the cycle will continue
– Offset drainages are streams displaced by faulting; they indicate the direction of relative displacement. The offset may reflect cumulative offset of several earthquake. Eventually the stream may erode a more direct route across the fault zone, producing a beheaded stream at the fault trace
– Linear valleys are troughs along main fault trace. These often develop because continued movement along recent fault traces crushes the rock, making it vulnerable to erosion. Streams commonly follow these zones of weakness
– Deflected streams are streams that enter a fault zone at an oblique angle and flow parallel to fault zones for some distance before returning to original orientation of flow
– River terraces are generally found in graded river. When a uplift occurs or base levels falls due to tectonic activity; river try to incise to reach to new graded profile and begin cutting new flood plain. In this manner; old flood plain become river terrace an inactive bench stranded over the new level of river. When down cutting of terraces are accompanied by regional tiling then tilted terraces are formed
– Geomorphic indices are the quantitative tools to understand the processes associated with any geomorphic element. Hypsometric integral, topographic asymmetry factor, stream length gradient indices, mountain sinuosity indices are a few geomorphic indices used for delineating landforms evolved primarily due to tectonic processes

15.4. Literature Review

The technique of interferometric synthetic aperture radar (InSAR) is used to examine small-scale features in the deformation field associated with the earthquakes. Satellite interferometry is based on multitemporal radar observations. InSAR is a method by which the phase differences of two or more SAR images are used to calculate the differences in range from two SAR antennae having slightly different viewing geometries to targets on the ground. As a result, displacements on the Earth's surface can be measured in a range of centimeters and millimeters. The InSAR results show significant deformation signatures associated with faults, fractures and subsidence. The interferogram also clearly indicates surface deformation related to earthquakes. First application of satellite interferometry for earth-quake research was demonstrated in '90 s by Massonnet *et al.*, (1993). The well-known ''butterfly'' image of the Landers earthquake (M = 7.3, 28 June 1992) was compiled on the basis of pre-seismic image of April 24, 1992 and post-seismic scenes: August 7, 1992; 3 July, 1992 and June 18, 1993. Similar images were obtained for the Kobe earth quake, Japan, date 16.01.1995, M = 6.8, Hector Mine earth quake, USA, M = 7.1, 16.10.99, Izmit earthquake, Turkey, 17.08.1999, M = 7.8 and others. All these cases demonstrate co-seismic and post-seismic deformations. There were no applications

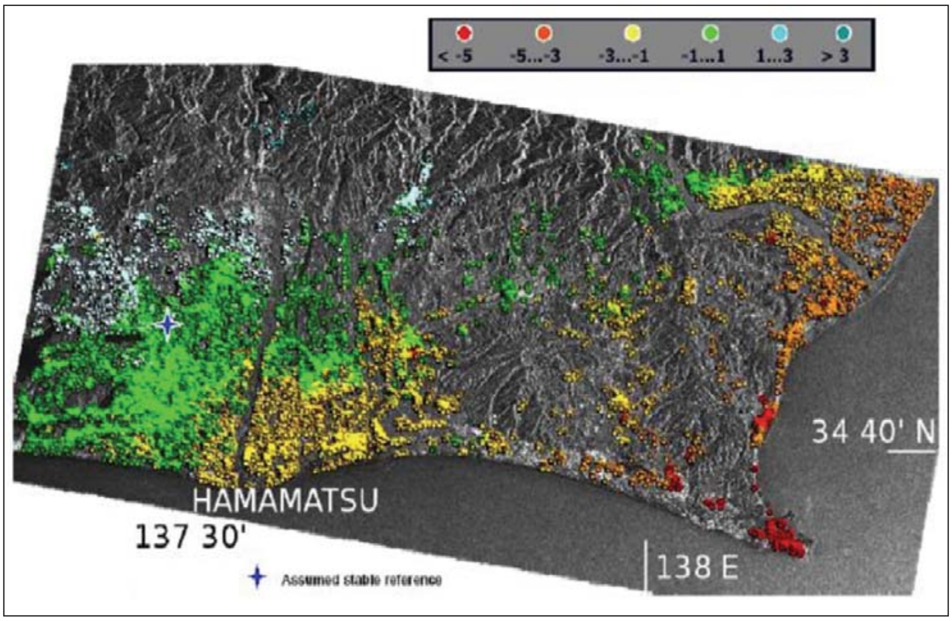

Figure 15.2: Average displacement rate 1992-2000 Years, mm/year (source: Kuzuoka and Mizuno, 2004)

showing the pre-seismic deformation. Only recent results from Japan (Figure 15.2) indicate probable pre-seismic deformation in the Tokai region (Kuzuoka and Mizuno, 2004). The vertical deformation recorded on the basis of InSAR data coincides with ground GPS observation.

Extensive researches have resulted to the identification of many precursors to the invincible earthquake phenomena. The latest one in the list of earthquake precursor that has been gaining a lot of attention and support from the scientific community across the world is thermal anomaly, i.e., a sudden rise in land surface temperature (LST) a few days or weeks before the earthquake occurrence. Prior to the earthquake event the region undergoes long preparation during which development of tectonic stress within the earth takes place. During this process various physical and electrical changes occur in the earth media. A change in the thermal regime of the epicentre region is one of the most prominent changes and can be detected by spaceborne sensors like Advanced Very High Resolution Radiometer (AVHRR) and MODIS. Pre-earthquake thermal anomaly and its spatial and temporal variations are controlled by various factors. Stresses acting before an earthquake in tectonically active regions generally increase ground temperature of the region. Such changes detected through thermal remote sensing can provide important clues about future earthquakes. Chowdhury *et al.*, (2007) demonstrated the capability of MODIS data in detecting the thermal anomaly related to earthquake in Iran. Panda *et al.*, (2005) detected the thermal anomaly just before the Kashmir earthquake.

The modern operational space-borne sensors in the infra-red (IR) spectrum allows monitoring of the Earth's thermal field with a spatial resolution of 0.5–5 km and with a temperature resolution of 0.12–0.5^{o}C. Surveys are repeated every 12 hours for the polar orbit satellites, and 30 minutes for geostationary satellites. The operational system of polar orbit satellites (2–4 satellites on orbit) provides whole globe survey at least every 6 hours or more frequently. Such sensors may closely monitor seismic prone regions and provide information about the changes in surface temperature associated with an impending earthquake. Natural phenomena and data availability stimulated the analysis of the long time series of thermal images in relation to earthquake hazard. Historically, the first application of thermal images in earthquake study was carried out in '80s for Middle Asia (Tronin, 1996). Later, similar researches were carried out in China (Qiang and Du, 2001), Japan (Tronin *et al.*, 2002), India (Singh and Ouzounov, 2003), Italy (Tramutoli *et al.*, 2001), Spain and Turkey, USA (Ouzounov and Freund, 2003) and other countries.

Thermal observations from satellites indicate the significant change in the Earth's surface temperature and near-surface atmosphere layers. Significant thermal anomalies prior to earthquakes related to high seismic areas have been reported in Middle Asia, Iran, China, Turkey, Japan, Kamchatka, India, Italy, Greece and Spain. Large volumes of thermal data were collected. Middle Asia database include seven years of observations for more than 100 earthquakes. Statistically significant correlation between thermal anomalies and seismic activity was observed (Tronin, 1996, 1999, 2000, 2002). Chinese scientists started operational earthquake forecast with spaceborne thermal measurements (Qiang and Du, 2001). The Destructive Bam earthquake in Iran took place on 26 Dec 2003. The magnitude of the earthquake was 6.6 and the city of Bam was destroyed. Before the earthquake the background distribution of the surface temperature was observed (Figure 15.3a) five days before the earthquake on 21 Dec 2003, and thermal anomaly was detected to the south of Bam city (Figure 15.3b). The observed thermal anomalies are related to the strong lithosphere-atmospheric coupling (Tronin *et al.*, 2004).

The causes of the thermal anomalies lie in the lithosphere and are related to the change of stress. The geological structures (faults, cracks, fractures etc.,) act as preferred conduits because the convective flow of fluids and gas in the upper levels of the lithosphere, and thereby the transport of heat, is one order of magnitude higher than the diffusive flow. The thermal anomalies are typically observed above large faults and their intersections. Depending on the geological and tectonic setting, near the surface, at depths of a few kilometers, the fluid is divided into water and gas. The water causes change of chemical composition in the wells and springs. Gas (H_2, He, CH_4, CO_2, O_3, H_2S moves to the atmosphere.The heat, water vapour and gas reach the Earth's surface, as a result of the lithosphere-atmospheric coupling. Few mechanisms of interaction are considered. First, convective heat flux (hot water and gas) changes the temperature of the Earth's surface. Second, change of the water level with usual temperature leads to a change in soil moisture, and consequently the physical properties of the soil. The difference in physical properties determines the different temperatures on the surface. Third is the greenhouse effect, when the optically active gases are escaped from the surface. Result of space borne thermal measurements for different areas looks similar: 1) thermal anomalies appeared about 6–24 days before and continued for about a week after an earthquake; 2) the anomalies are sensitive to crustal earthquakes with magnitude greater than 4.5;

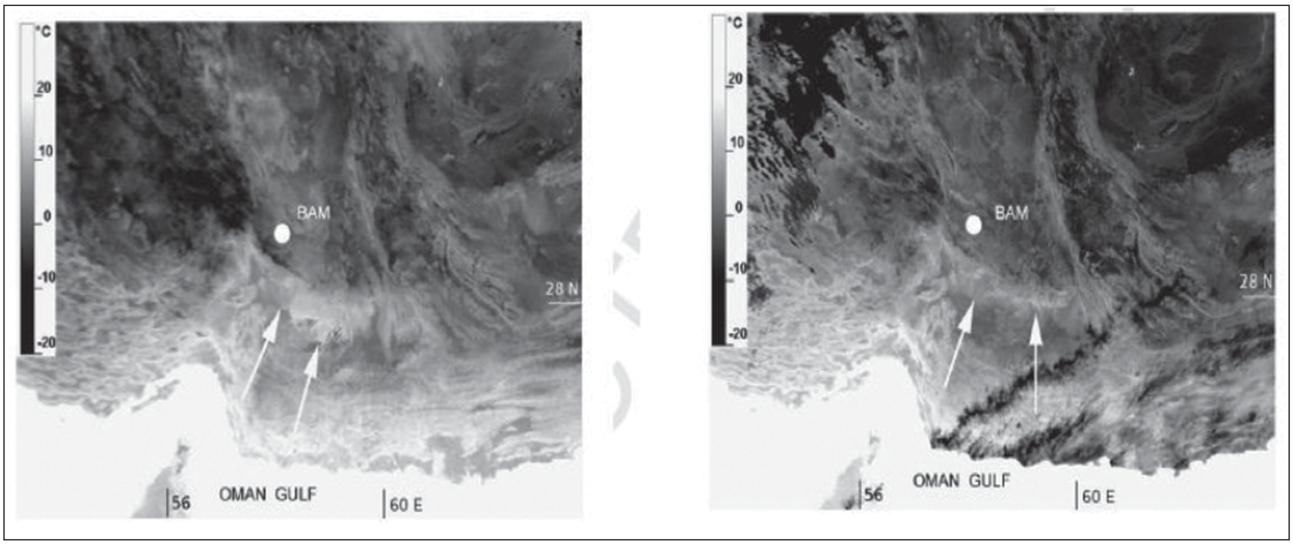

Figure 15.3: (a) NOAA thermal image , South Iran, background situation, 23 December, 2003. Arrows shows thermal anomaly and white circles Earthquake epicenter on 26th December, 2003. (b) NOAA thermal image 25 December, 2003. (Source: Tronin,2006)

3) thermal anomalies are attached to large faults; 4) the response of water in wells and surface temperature in thermal anomaly on earthquake look similar; 5) increase of air and surface temperature as a consequence of the hot water eruption a few days before strong earthquakes could lead to atmospheric perturbations (atmospheric gravity waves) and could be helpful to explain an origin of some preseismic electromagnetic effects (in the ULF, VLF, LF frequency range) (Gokhberg *et al.*, 1982; Hayakawa and Molchanov, 2002).

Case studies on various remote sensing applications for earthquakes have been reported recently. Pinty *et al.*. (2003) have found the significant emergence of surface moisture growth after the Gujarat earthquake, 26 Jan 2001, using MISR data. Dey and Singh (2003) found significant surface latent heat flux change prior to the Gujarat earthquake. Dey *et al.*, (2004) found a change in the total water vapor column after the Gujarat earthquake. Water content was retrieved by SSM/I microwave radiometer on Tropical Rainfall Measuring Mission (TRMM) satellite. Okada *et al.*, (2004) found changes in atmospheric aerosol parameters after the Gujarat earthquake. Aerosol above sea surface was recorded by SeaWiFS satellite. Singh *et al.*, (2002) found changes in water colour and Earth's surface related to the Gujarat earthquake using IRS satellite data. A few examples of ozone concentrations changes measured by TOMS related with earthquakes are reported by Tronin (2002).

The use of satellite-based remote sensing technology for seismic risk mitigation purposes goes back to early 70s. One of the first related techniques that can be mentioned is "Side-Looking Radar Imagery" (Kedar and Hsu, 1972). In recent decade more attention has been paid to the use of remote sensing for natural hazards mitigation, and it has been claimed that remote sensing has a unique role in natural hazard assessment and mitigation (Wadge, 1994). Airborne and satellite are among the newly developed ones for gathering information on damage due to earthquake (Yamazaki *et al.*, 1998; Matsuoka and Yamazaki, 2000).

A similar damage detection study was carried out on the 1999 Kocaeli, Turkey earthquake (Estrada *et al.*, 2000) by using Landsat/TM images. Another similar study has been done with regard to 2001 Gujarat, India earthquake (Yusuf *et al.*, 2002). The damage of 2001 Bhuj, India earthquake has been also studied through a multidisciplinary approach based on high resolution satellite imagery (Chiroiu *et al.*, 2002). It has been claimed that the results could be very useful for the rescue teams deployed immediately after the catastrophe. Very recently in an MCEER publication a study has been reported entitled "Resilient Disaster Response: Using Remote Sensing Technologies for Post-Earthquake Damage Detection" (Eguchi *et al.*, 2003). Eguchi and his colleagues have studied the damages caused by the 1999 Marmara (Kocaeli), Turkey earthquake. The proposed techniques have been claimed to an effectively employed to determine the extent of damages in urban buildings. However, their results show that their techniques are basically useful for heavily damaged buildings rather than moderately or slightly damaged ones. This can be considered as a limitation in the use of their proposed techniques. Teeuw (2007) demonstrates as to how various types of remote sensing technique can be applied to mapping and monitoring riverine and coastal geohazards. The study focuses on flooding, ground instability, erosion and sedimentation, mainly drawing on examples from the UK. The study has shown as to how remote sensing offers a wide range of useful techniques for mapping coastal and riverine features, especially in inaccessible terrain. Seismic hazard assessment requires knowledge not only of the earthquake sources and propagation of seismic waves, but also of the effect of local geology on earthquake ground shaking. However, the lack of empirical data for efficient earthquake microzonation tools have precluded integration of local site effects into earthquake hazard assessment schemes. Therefore, simple and fast methods for first-order site classification are being developed, as well as methods based on rapid surveys of seismic noise and combined with shallow geophysical investigations. Advanced methods of seismic noise analysis suitable for near-surface investigations are also being developed and tested.

15.5. Gap Areas

The low revisit frequency of thermal and DinSAR satellites limits the use of advance remote sensing technology in earthquake prediction and deformation monitoring-related studies. The observations made by satellites needs to be validated with more ground-based observations detecting anomalous soil moisture concentration, thermal anomaly, radon gas concentration for improving the accuracy of the methods can be enhanced. Moreover, low visit frequency of high resolution data limits the use of satellite data in post-earthquake damage assessment. Moreover, the lack of empirical data on various geophysical parameters influenced by earthquake deformation is main obstacle information for efficient earthquake microzonation. Suitable models needs to be developed which can incorporate satellite-based and ground information to provide accurate seismic micro zonation.

15.6. Case Study

A case study on the use of remote sensing for assessment of Post earthquake damages that occurred in 8th october, 2005 in J & K.

An earthquake of magnitude Mw=7.3 (USGS) ML=7.4 (IMD), Ms=7.6 (USGS) shook entire Northern India at 9.30am on Oct 8, 2005. The preliminary location of the earthquake epicenter was close to Muzuffarabad of Pak administered Kashmir and west of Uri Sector of Baramullah district. The severe shaking has been felt in most of the Northern India which includes Jammu and Kashmir, Uttarkhand, Himachal Pradesh, Rajastan state in the range of several hundred kilometers from the epicenter. People in Srinagar, New Delhi, Chandigar, Ajmer cities came out of their houses and the duration was about 40 to 70 seconds. Several people have experienced significant shaking in southeastern part of New Delhi and some of them witnessed sway in tall buildings. Massive destruction has been reported in Uri sector where one of the villages has been completely destroyed and a report of fire causing damage to some houses has been reported. The 200 year old Moti Mahal fort at Poonch district has been reported to be completely destroyed. At least 39 people which includes 15 soldiers have been killed in the Kashmir region of India (Source: Press Trust of India). Over 300 injured as more than 400 houses were flattened in J&K after a massive earthquake that also jolted Pakistan claiming at least 35 lives and injuring hundreds there, after a 19-storey building collapsed in Islamabad (Source: DD News). The Pakistani media has reported that the destruction has been severe in Islamabad.

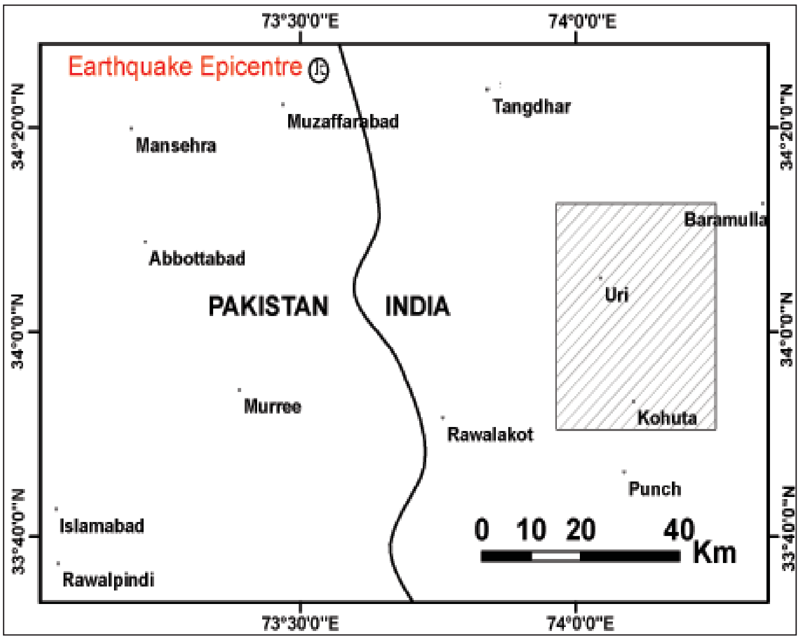

Figure 15.4: Study area map

Objective

- Geological assessment of the earthquake
- Damage assessment of the earthquake

15.6.1. Study Area

Geological assessment was carried out for a larger area covering the epicentre (Muzzaffarabad) using AWIFS, LISS-3 and LISS-IV data – (Figure 15.4). Damage assessment was carried using stero-cartosat data.

15.6.2. Data Used

The following data has been used for the study :-

- LISS-IV Mx data for the most damaged Uri sector was acquired by tilting the camera on 9th October,2005
- AWiFS data acquired on 9th October 2005
- No IRS-P5 data coverage for this area on 8th October and hence it was tilted for 9th October,2005 for Uri sector

15.6.3. Analysis

15.6.3.1. Geological Assessment

Geological assessment was carried out using the satellite data and published seismo-tectonic atlas by GSI (2000) and the USGS report on the earthquake (2005). AWiFS data having a wider spatial coverage was co-registered with the published seismo-tectonic map and the boundaries were transferred to satellite image. The boundaries were updated using the image expression. The past and the present epicentre were plotted on the satellite data. There are basically two major tectonic elements which has played a major role for this earthquake. These are main central thrust and the Jhelum strike slip fault. Earthquakes and active faults in northern Pakistan and adjacent parts of India and Afghanistan are the direct result of the Indian subcontinent moving northward at a rate of about 40 mm/yr (1.6 inches/yr) and colliding with the Eurasian continent. This collision is causing uplift that produces the highest mountain peaks in the world including the Himalayan, the Karakoram, the Pamir and the Hindu Kush ranges. As the Indian plate moves northward, it is being subducted or pushed beneath Eurasian plate. Much of the compressional motion between these two colliding plate has been and continues to be accommodated by slip on a suite of major thrust faults that are at the Earth's surface in the foothills of the mountains and dip north beneath the ranges. These include the Main Frontal thrust, the Main Central thrust, the Main boundary thrust, and the Main Mantle thrust. These thrust faults have a sinuous trace as they arc across the foothills in northern India and into northern Pakistan

15.6.3.2. Tectonics Framework of the Kashmir Region

The epicenter was located very close to Shinkiari fault and north of Jhelum fault which is regionally most extensive and it separates Kashmir basin of India from the Peshawar basin of Pakistan. From north to south, three main thrust system exists. The northernmost is the Main Karakoram Thrust (MKT). Towards south, it is separated from Peshawar and Kashmir basin by the Main Mantle Thrust (MMT). The southernmost is the Main Boundary Thrust (MBT), which separates the main Himalayan system from the sedimentary sequence of the frontal belt. The local geology strongly points the possibility of large amplifications of ground motion due to the influence of Peshawar basin and basin edges near Jhelum fault. The region is moderately active and has experienced several earthquakes of magnitude greater than 5.0 during last 300 years. The largest earthquake occurred on 30th May 1885 (Kashmir EQ) 19.5 km west of Srinagar and took 3000 lives. The earthquake of Badgam (M5.1) on 2nd Sept 1963 and Pattan earthquake (M5.9) on 28th Dec 1974 was deadliest and has affected several towns in the region which includes Indus Kohistan and Swat region. The Karakoram highway was reported to be badly damaged during this earthquake (Source: GSI 2000).

The AWiFS data analysis has highlighted the following important changes. A set of landslides has developed along the main central thrust and jhelum Fault.

15.6.4. Damage Assessment

A detail damage assessment was carried out using PAN stero + Cartosat-1 data. The area coverage was limited by the tilting of the camera. Monoscopic and stereoscopic analysis was carried out to assess the damages. Uri and Baramaulla sector of J& K was considered for damage assessment since it is nearer to epicentre.

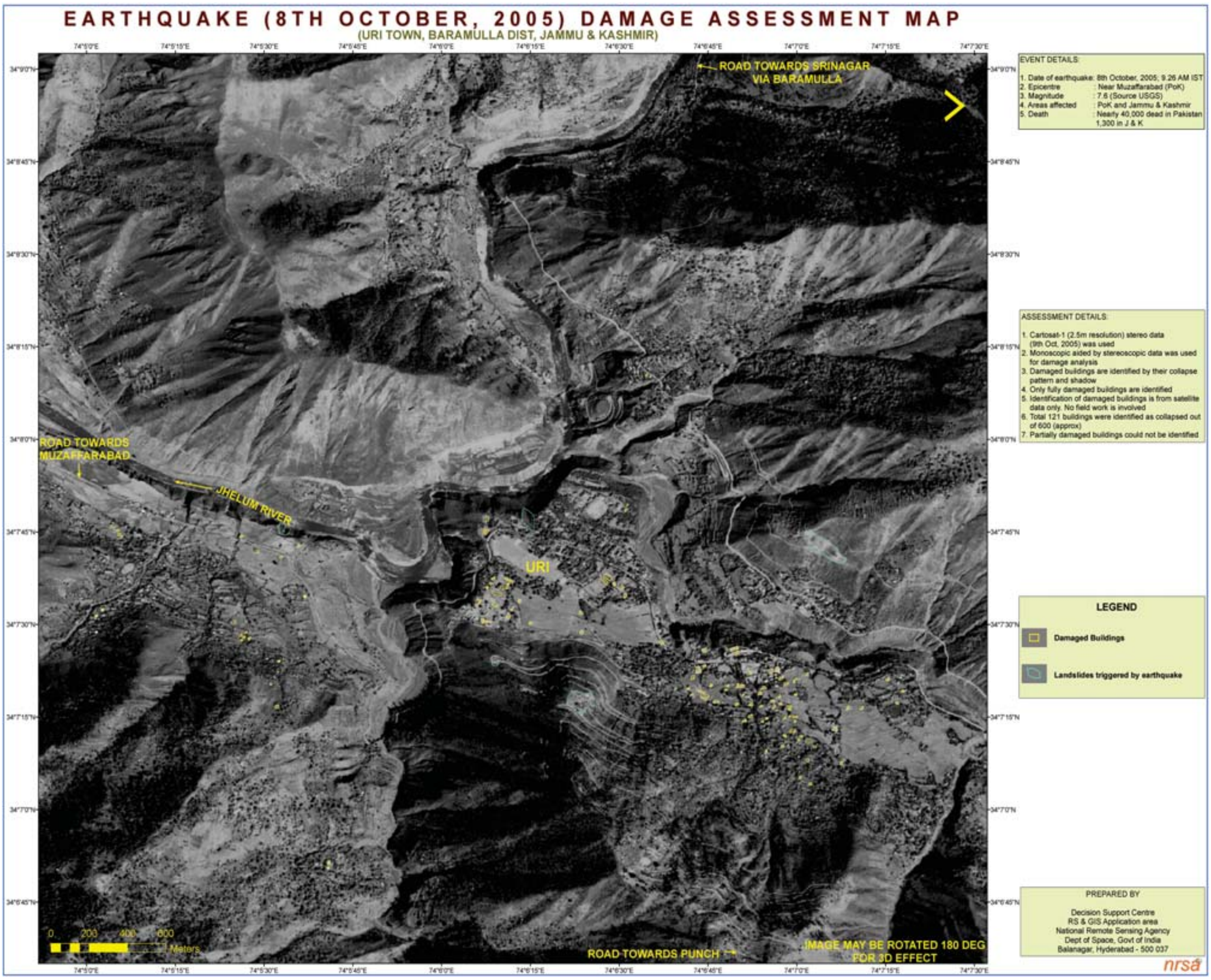

Figure 15.5: The Damaged Building/infrastructures in Uri town, Baramulla District, Jammu & Kashmir due to Earthquake- identified from high resolution Satellite image

The damages were classified into (Figure 15.5)

- Collapsed building
- Infrastructure damage especially roads , bridges and any other vital installations

15.7. Future

Advancement in DinSAR technology will allow us to record very fine differences in surface displacement. The COSMO/SkyMed mission aims at providing daily observations from 2007, overcoming limited observational frequency by using a constellation of four satellites. Existing satellite INSAR instruments have C- band (a wavelength of 5.66 cm) offering high resolution, but they only provide reliable interferograms for coherent, non-vegetated surfaces. Data from the JERS-1 satellite demonstrated during its lifetime that L-band satellites offer reduced resolution but provide interferograms over a far greater range of surface cover types.

Furthermore, the role and the applicability of remote sensing techniques with the aim of mapping the topography gradient as a proxy would be an important aspect of study. Investigating the role of “soil-city” interaction for local ground shaking and assessing the effect of ground motion duration on earthquake damage are additional challenging issues that have found no or only inadequate consideration in previous microzonation studies. Studies related to adequate magnitude determination, wave propagation, and ground motion prediction equations are also being integrated. On the other hand, recent earthquakes in Turkey and India showed that the main cause of human casualty in developing countries due to earthquake is the collapsed buildings. Therefore, it is quite reasonable for developing countries to plan for conjunctive use of optical and SAR systems for detection of collapsed buildings. This will provide the emergency management authorities with the more reliable information on the casualties distribution, which is a key point in the success of disaster mitigation actions.

15.8. Summary

Remote sensing can play an important role in earthquake prediction, seismic microzonation and post earthquake disaster management-related studies. The major limitations of remote sensing based earthquake studies is ascribed to rare validation of satellite based measurement with ground data and the lack of consistency in trend in the relations of observed anomaly with the earthquake. The high repetitivity, varied satellite-based observations are required for earthquake related studies of all relevant domain such as prediction, seismic zonation and post-earthquake disaster management.

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