On The Use of Remote Sensing and GIS Techniques in Post Earthquake Damage Identification and Assessment in Pakistan

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Abstract: *A recent earthquake in Pakistan on October 08, 2005 of 7.6 magnitude with a death toll of 80,000 people, is one of the most disastrous events of this century. This unprecedented catastrophe needs scientific studies for the post earthquake damage assessment. Undertaking damage identification and assessment for large areas is very expensive; consequently for reconstruction it is important to identify the areas, which are less vulnerable to seismicity. The capability to undertake earthquake damage identification and assessment can be improved through current advances in Remote Sensing and GIS technologies. As a test case we have conducted a field visit of Garhi Habibullah to conduct GPS survey with the application of European Macroseismic Scale (EMS). The main objectives of the study:1) To investigate the role of satellite Remote Sensing (SRS) data in post earthquake damage assessment through visual interpretation;, 2) To analyze post earthquake damage in Garhi Habibullah and its environs by using high resolution satellite imageries; and 3) To develop "seismic zones" intensity map for entire Pakistan by using GIS interpolation techniques. This study would become a preamble for an in-depth study that will be based on Geological/Social parameters like base-rock motion, soil strengthening, slope failure, construction susceptibility and socioeconomic indicators that identifies high and low risk zones at local level for rehabilitation and reconstruction activities.*

Background

On October 8, 2005 at 0850 local time, an earthquake of magnitude 7.6 on Richter Scale occurred in northern Pakistan, which caused widespread devastation. It is relatively large area of about 28,000 sq. Km. covering four districts of Azad Kashmir: *viz* Neelum Valley, Muzffarabad, Bagh and Rawalakot, and five districts of Hazara Division of NWFP, namely, Indus Kohistan, Balakot, Batagram, Manshera and Abbotabad (Ahmad, 2005).

As of March 31, 2006, the total casualty figures in Pakistan alone stood at 75,000 deaths and 75,000 injuries, close to 400,000 homes were fully destroyed and damaged leaving about 3.5 million people shelterless (Government of Pakistan, 2005). The heaviest damage occurred to cities of Muzaffarabad and Balakot that were in proximity of the fault rupture responsible for the earthquake. Ground shaking was felt as far south as Islamabad, resulting in one spectacular building collapse. Heavy damage was also reported from the Indian side of Kashmir. Furthermore, the ground shaking caused numerous landslides and rockfalls to be triggered that damaged roads and bridges, blocking access to heavily damaged areas and hampering the relief effort. This is the biggest ever catastrophe in the recent history of Pakistan. It is not difficult to gauge the extent of devastation; the entire human habitation has been reduced to heaps of rubble. The official estimate of 75,000 dead may be true of the day it was announced. The actual number may exceed to 100,000 to 150,000 (Ahmad, 2006). As it is obvious from the Table-1 that the earthquake took a very heavy toll on the inhabitants of Kashmir and NWFP.

Table. I Toll of Earthquake

Deaths	75,000 persons (this includes over 18,000 children)
Injured	70,000 persons
Overall affected	3.2- 3.5 million persons
Without Shelter	2.8 million persons
Without adequate food	2.3 million persons
Employment loss	325,000 persons (30%)
Housing	400,153 shelter units destroyed or seriously damaged.
Educational Institutes	2647 (damaged) & 4844 (destroyed)
Health Institutes	455 (damaged) & 119 (destroyed)
Roads	4429 km (damaged) (37%)

Source: Government of Pakistan (2005)

This earthquake is an eye-opener both for public and academia to study this calamity and aftereffects of this natural hazard, in such a manner that future losses could be avoided. In this paper author would like to present a brief overview of seismicity in Pakistan and to explore the role of Geoinformatics to for the damage assessment in Pakistan.

Study Area

Garhi Habibullah is located in the North-East of the Manshera District bordering Muzaffarabad district of Azad Jammu and Kashmir. This area is chosen as the study area because of the proximity to Islamabad and availability of high resolution data on google-earth, which is freely downloadable from the internet. On October 8, 2005 this small city severely affected by the earthquake, both public and private buildings and infrastructure damaged significantly. However, during our visit we have found that even after the six months after the calamity. People are still leaving either on the rubble or in Refugee Tented Villages (RTVs), still waiting for their assistance to rebuild their houses. Nevertheless, public buildings like schools has been constructed by the Government at faster pace. One neighborhood of Garhi Habibiullah surveyed with the help of blue-tooth GPS connected through a laptop. Euopean Microseismic Scale (EMS) used to calibrate the building codes according to the impact of October 8, earthquake.

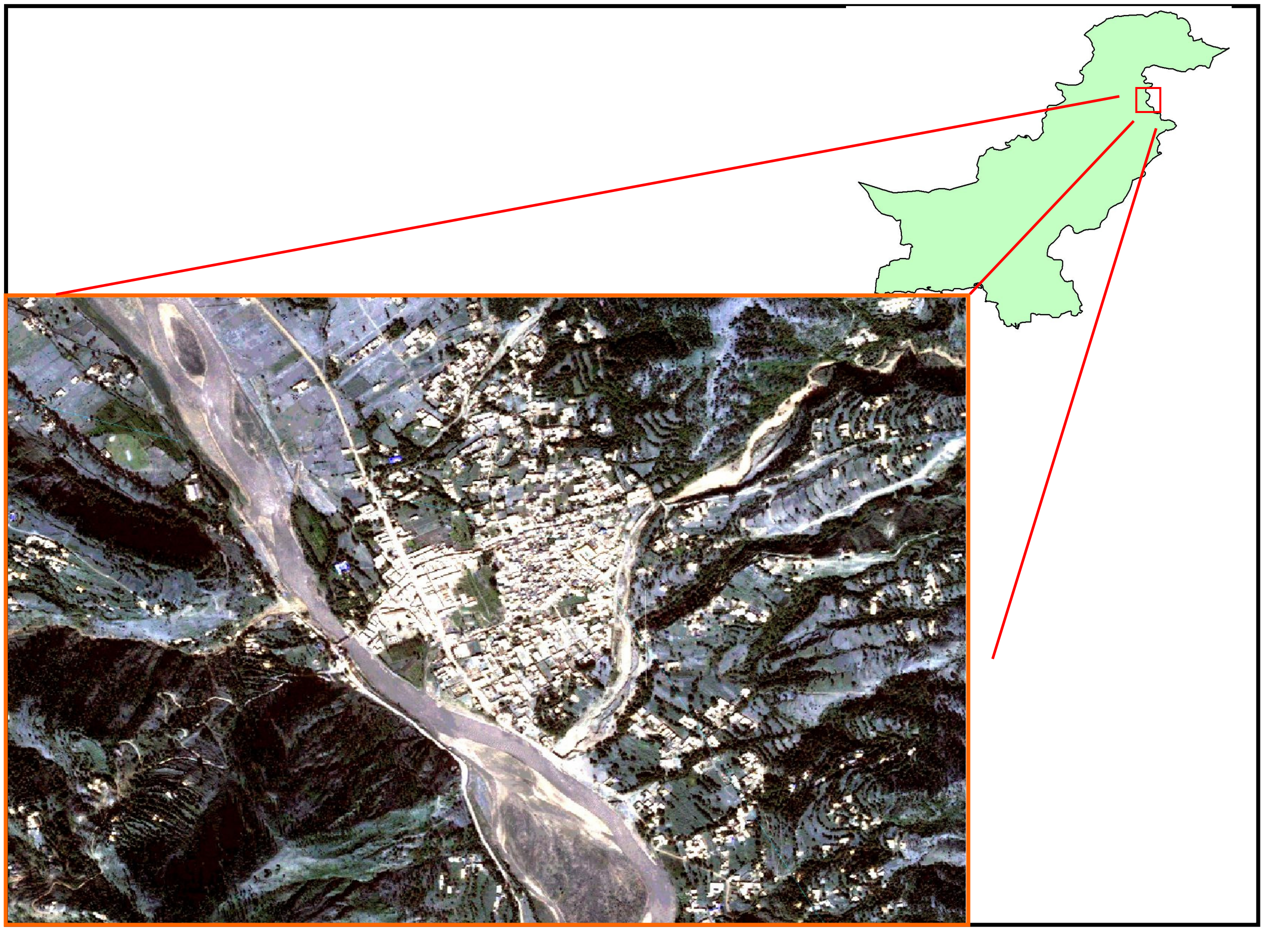


Figure-1: Study Area (Garhi Habibullah)

Seismicity in Pakistan

The geologic forces that triggered the powerful quakes also shaped the rugged, mountainous region shown in Figure-2. Geology in northern Pakistan and India is controlled by the motion of the Indian subcontinent as it is shoved under the Asian continent at a rate of about 40 millimeters (1.6 inches) per year. As the continents collide, they push up the highest mountain ranges on the planet: the Himalaya, the Hindu Kush, the Karakoram, and the Pamir (Figure-3). The friction also breaks the Earth's solid surface into an intricate series of faults. All of these fault lines are noticeable in the North and West of Pakistan (Figure-4). Like the spidery veins that radiate from a crack in glass, the faults are connected, but are sometimes hard to trace. As the piece of the Earth's crust on which India sits moves, tension builds in the faults. Eventually, the faults slip, releasing their tension and giving vent to an earthquake. As the tension is redistributed, the ground shakes along adjoining faults or along other sections of the same fault in a series of aftershocks.

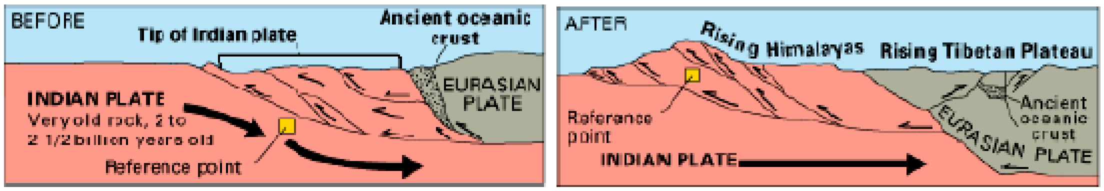


Figure-2: The Convergent Margins in between Eurasian and Indian Plates in the North of Pakistan (USGS, 2005).

Suprisingly enough with this heavy toll the earthquake was totally a surprise for both the government and people of Pakistan. From the relief and rescue operations it was also clear that both governmental agencies and public were not ready to handle this gigantic calamity. Nevertheless, it is evident from the Figure-2 & 3 that most of the area of Pakistan is under seismic threat and areas of Kashmir and NWFP are most highly active area tectonically.

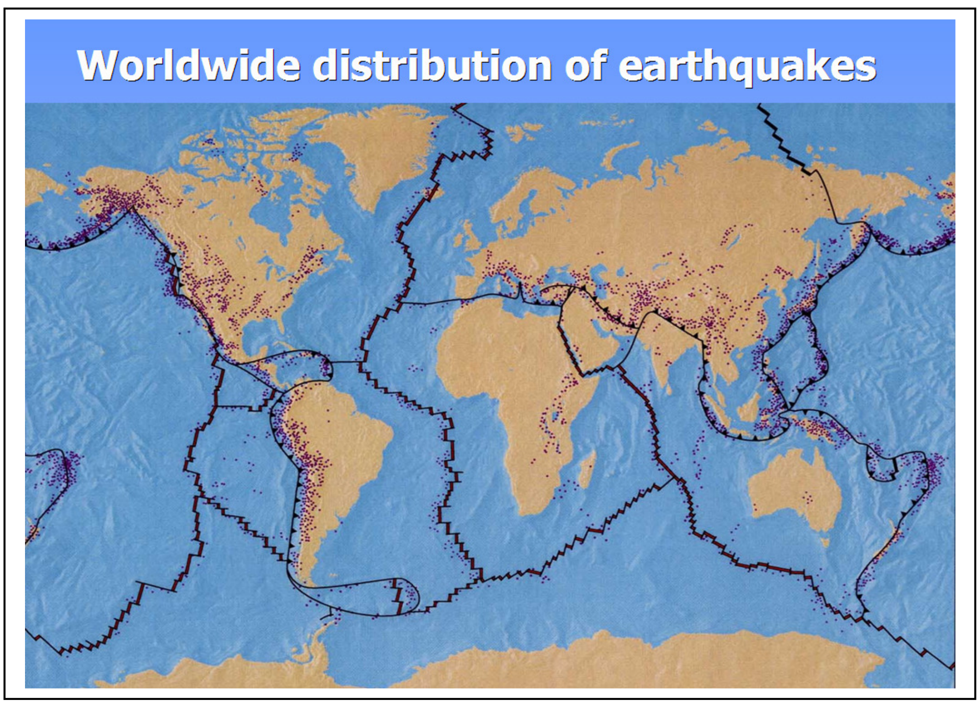


Figure-3: Pakistan the meeting place of three tectonic plates, viz., Eurasian, Indo-Australian and Arabian plates.

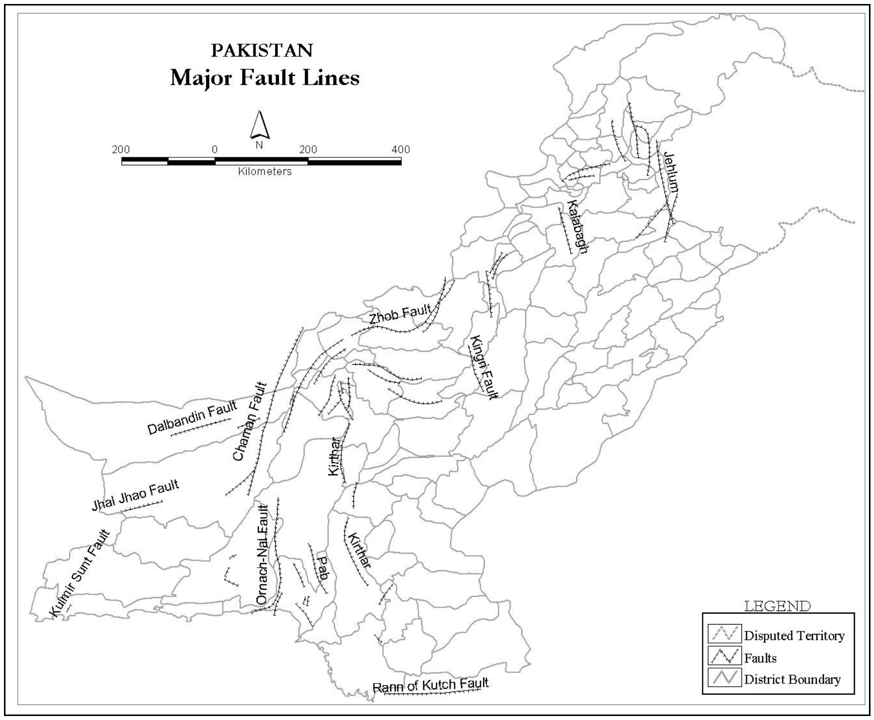


Figure-4: Major Fault Lines in Pakistan

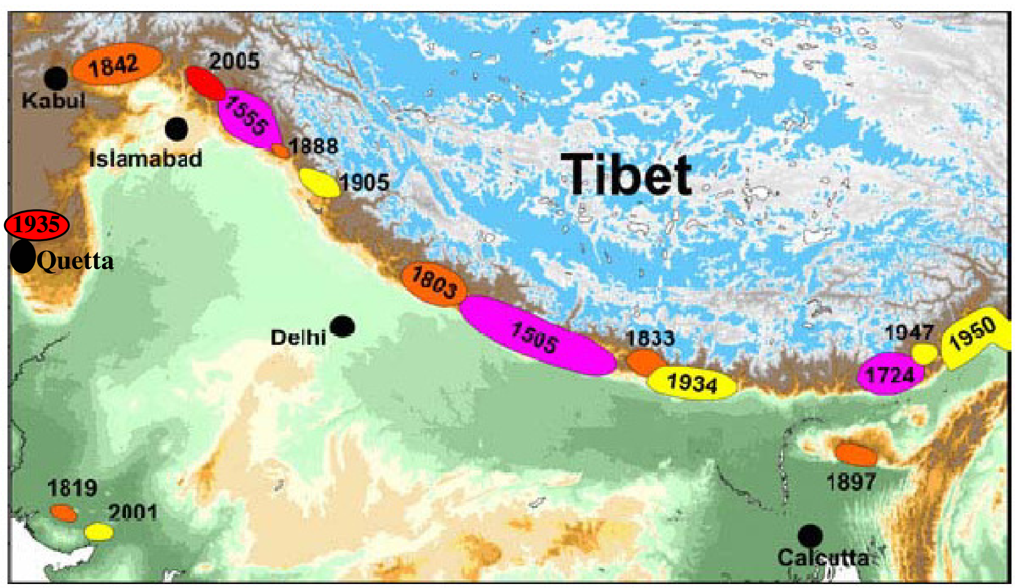


Figure-5: Catastrophic Earthquakes in and Around Pakistan (After Bilham, 2005)

Role of Geoinformatics in Earthquake Management

The use of Geoinformatics is, for a number of reasons, becoming increasingly widespread following natural disasters. On a policy level, international initiatives such as the 2000 Charter on Space and Major Disaster (International Charter, 2003) constitute a significant commitment towards the use of space facilities for emergency management. In terms of data accessibility, programs including the European Space Agency. Earth Watching Service now freely distribute satellite disaster coverage (ESA, 2003). Remote sensing also has a proven track record in the aftermath man-made events like the World Trade Center attack (Huyck and Adams, 2002) and Columbia space shuttle disaster (NOAA, 2003). These factors combined with investment in applied research from organizations such as the Multidisciplinary Center for Earthquake Engineering Research (MCEER), are facilitating its deployment through progressive end-users, like the Earthquake Engineering Research Institute (EERI) reconnaissance team (Adams *et al.*, 2004).

For decades, geoinformatics (integration of Remote Sensing, GIS, GPS and Surveying techniques) has played a vital role in grasping damage information because of the earthquake. Medium resolution satellite data like SPOT, Landsat (Eguchi et al., 2003; Yusuf et al., 2001) or ERS (Matsuoka and Yamazaki, 2004) is mainly concerned to identify the damage extent and distribution. Damaged buildings can be detected by using the aerial photographs (Hasegawa et al., 1999). The use of RST 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 RS for natural hazards mitigation, and it has been claimed that RS has a unique role in natural hazard assessment and mitigation (Wadge, 1994). Airborne and satellite RSTs are among the newly developed forms for gathering damage information (Yamazaki et al., 1998; Matsuoka and Yamazaki, 2000). In those studies, Yamazaki and his colleagues by using Pre and Post satellite data in 1995 for Hyogoken-Nanbu earthquake have examined the accuracy of several imageries from the viewpoint of detection of buildings damage.

A similar damage detection study has been performed 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 in a multidisciplinary approach based on high resolution satellite imagery (Chiroiu et al., 2002). Their study provides a quick loss estimation method in terms of physical damage and human casualties. It has been claimed that the results could be very useful for the rescue teams deployed immediately after the catastrophe.

Recently, high-resolution imagery of commercial satellites such as IKONOS and QuickBird, which can readily be acquired, becomes more powerful information of natural and/or man-made disaster at an early stage. Following those attempts, in this study, author investigate the Remotely sensed data and its derived information can be explores in a more attractive mean to strengthen public awareness in disaster mitigation.

Virtual reality using remotely sensed data has been widely employed to assist regional and local planning (Zhang et al., 2002), making digital cultural heritage (Gruen and Wang, 2002), natural resource management (Dunbar, 2003) and many others.

In case of post-earthquake urban damage assessment, remotely sensed data offers profound advantages over traditional methods of field survey – it is low-risk, and offers a rapid overview of building collapse across an extended geographic area. Accordingly, damage detection techniques are now appearing in the literature, employing either indirect or direct methodological approaches. For example, urban damage is inferred from a surrogate measure such as night-time lighting levels (Hashitera *et al.*, 1999 and Kohiyama *et al.*, 2001). In the latter, building damage is recorded directly, based on its distinctive signature within the imagery Matsuoka and Yamazaki, 1998; also Chiroiu *et al.*, 2002). Direct approaches may be categorized as mono and multitemporal. Monotemporal analysis detects damage in imagery acquired after the disaster has occurred (Ogawa and Yamazaki, 2000; Hasegawa *et al.*, 2000; Chiroiu and Andree, 2001; Mitomi *et al.*, 2002). The multitemporal technique instead assesses damage based on spectral changes between images acquired at several time intervals; typically 'before' and 'after' an extreme event. Eguchi et at. (2000) presents a multitemporal change detection algorithm for determining the location and severity of post-earthquake building damage. Section 2 introduces the methodological approach, while Section 3 describes its implementation for the 1999 Marmara (Turkey) and recent 2003 Boumerdes (Algeria) earthquake.

Satellite Remote Sensing (SRS) data has been used in many developing countries as well, including Pakistan for many purposes, particularly environmental resource evaluation and meteorological forecasting. Although Pakistan is situated in earthquake prone regions, still there is slight development in the use of this technology for seismic warning purposes. One of the main reasons behind this fact is the lack of knowledge in disaster management of the authorities with respect to SRS. The slowness and inaccuracy of this technology, the complexity of earthquake phenomenon and its sequences, the low resolution of satellite Remote Sensing (RS) images, and repetition cycle are among the factors that constrain the use of this technique in earthquake disaster reduction. Nevertheless, the recent developments in SRS and the potentials of this technology for serving the disaster mitigation activities support the thought of using it for early warning purposes. It should be noted that the early warning concept of earthquake is different from what is usually meant by it in other natural hazards. In fact, instead of using the RST for predicting the time of an earthquake occurrence, which is actually impossible, this technology can be used for earthquake disaster early warning, by providing the disaster management authorities with the reliable information about the extent of damage to buildings and facilities in stricken areas (Hosseini and Izadkhah, 2004).

Development of Seismic Risk Zones of Pakistan through GIS Techniques

With the help of United States Geological Survey (USGS) and Geological Survey of Pakistan (GSP) seismic data for the last 100 years the seismic zones of Pakistan were developed. This dataset first tabulated in an Excel sheet in xls format, the dataset contains the latitude and longitude of the earthquake location and its magnitude in the Richter Scale. The data is imported in ArcView 3.2 as add event theme as a point shape file. Figure-6a depicting the distribution of the earthquake in Pakistan and showing the intensity of the earthquake in accordance with the Richter Scale magnitude. Graduate dot symbols showing intensive earthquake areas in the North-East of Pakistan, North West and South West of Balochistan. These dots were then interpolated with the help of IDW (Inverse Distance Weight) technique in Spatial Analyst. The result of this interpolation is shown in Figure-6b. The results were further refined in Figure-6c and divided into four zones categories according to the risks, from very low seismic risk to extremely high, again high risk regions are located in Balochistan and North East of Pakistan.

High spatial resolution satellite data like QuickBird providing the data on 0.61m. Similarly, temporal resolution of satellite data (repeat frequency) also increase to one day in case of FORMOSA-1 satellite with spatial resolution of 1m.

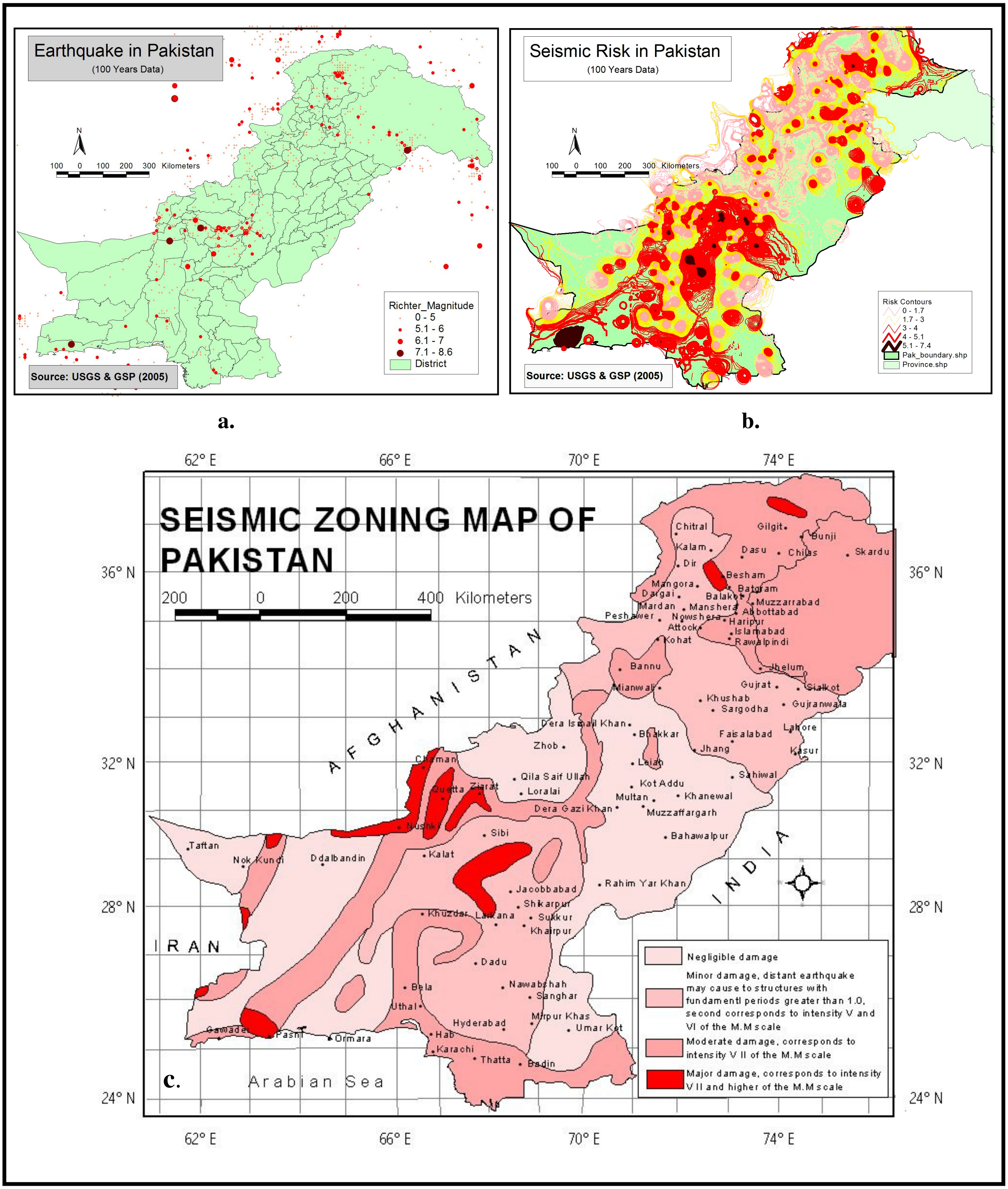


Figure-6: Development Stages of the Seismic Risk Map of Pakistan

Visual Interpretation of Satellite Data

For visual interpretation we selected three types of satellite data from medium to fine resolution. On medium resolution Landsat 7 images for pre and post earthquake were chosen and downloaded from NASA's website. Even on this resolution the impact of earthquake is very prominent (Figure-7), in the pre earthquake image of November 2000 not a single landslide is noticeable, however, same area in the December 2005 is heavily occupied with the multiple landslides. On higher scale and zoom-in the same area near River Jehlum (Muzaffarbad) landslide is easily identifiable on IKONOS 1 meter resolution data (Figure-8). Not only landslide but also debris in the river is obvious and the color of the River Jehlum changed completely from blue to rock brown. On the same image devastation of the buildings is also evident. Another example of using remote sensing technology in building damage assessment is highlighted in Figure-9, where a building near AJK University is intact in pre earthquake image of IKONOS 1 meter and totally dismantled in post earthquake image.

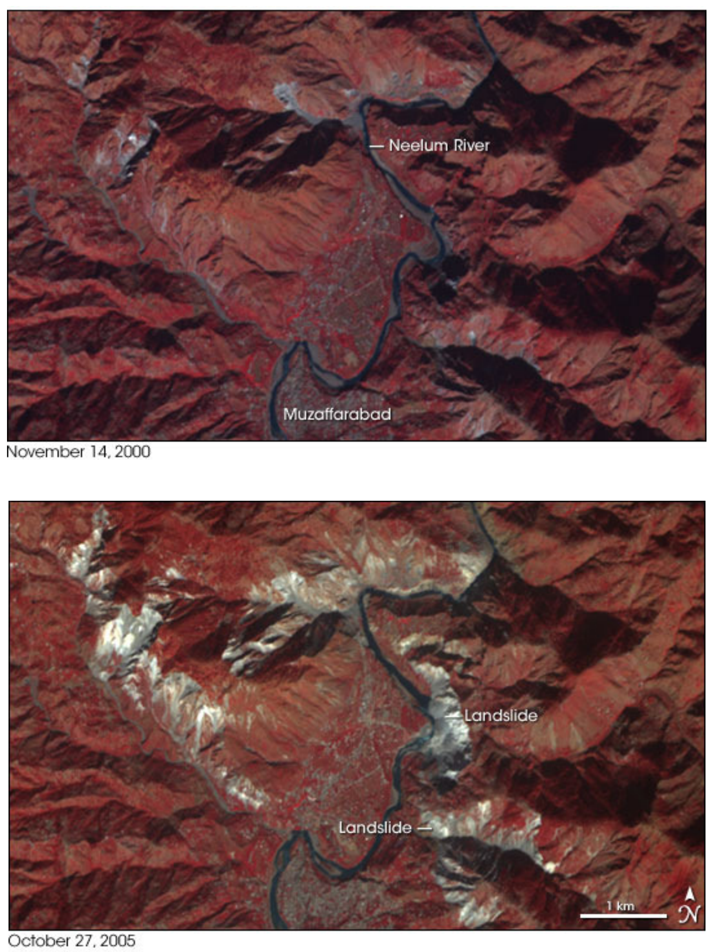


Figure-7. Pre and Post Earthquake Landsat-7 Images of Muzaffarabad & Adjoining Areas (Carayannis, 2005)

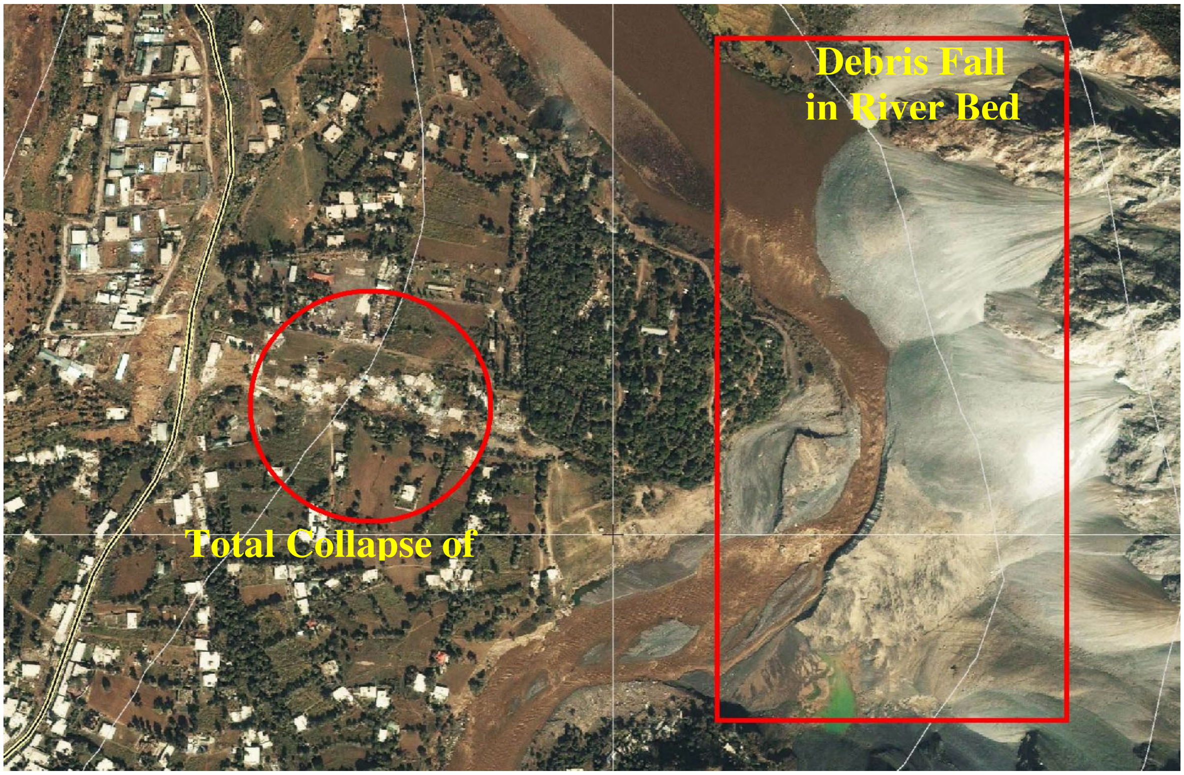


Figure-8. Post Earthquake IKONOS Image of Jehlum River (DLR, 2005)

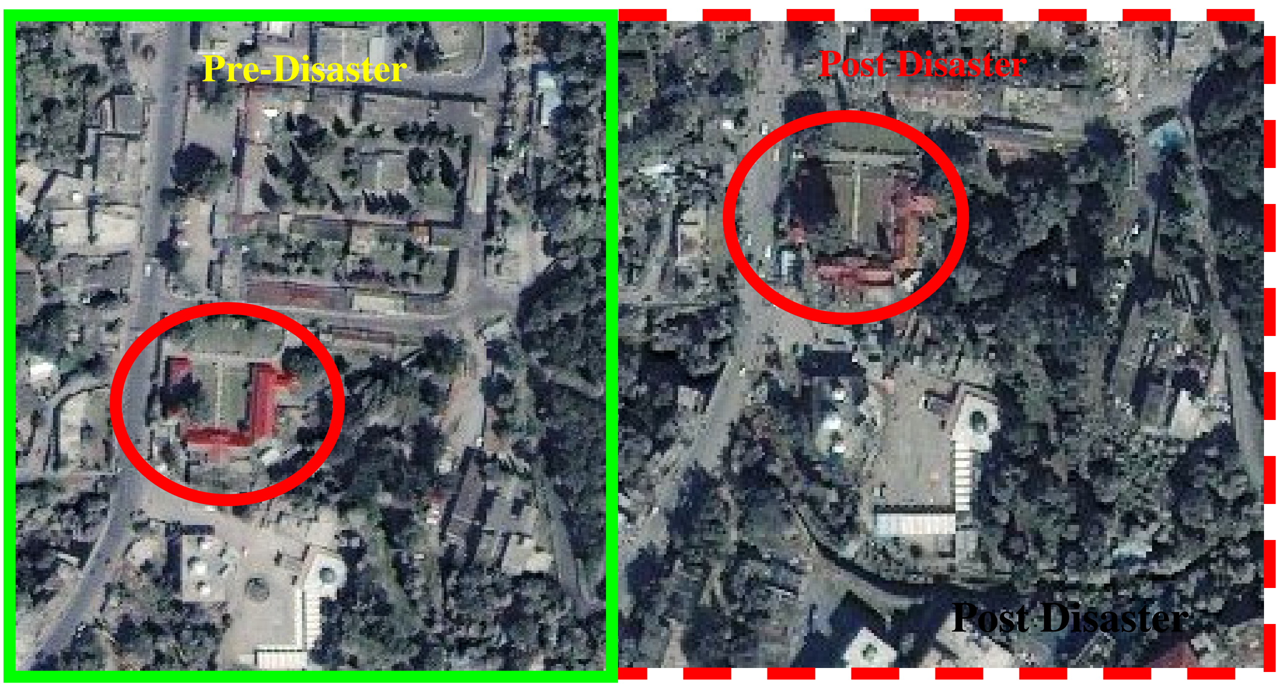


Figure-9. Pre and Post Earthquake Images of Muzaffarabad on IKONOS Imageries (Space Imaging (2005)

Case Study of Garhi Habibullah

As mentioned in the study area the town of Garhi Habibullah was chosen to conduct a reconnaissance survey to note down the impact of earthquake. However, before visiting the field European Macroseismic Scale completely decoded for the local buildings. Most of the buildings in the affected area were fieldstone, adobe and simple stone masonry (Table-2). A handheld GPS unit attached with a laptop computer through a Bluetooth is used to mark the coordinates of the affected buildings. Each surveyed buildings is coded with EMS and its coordinates in UTM projection were saved. The sample of each category from low vulnerability to extremely high vulnerable class is also documented through digital ground photographs (Figure-11).

The same surveyed area is then downloaded through google-earth website, which has only post disaster images of QuickBird data on 61 cm spatial resolution. The image of this resolution is highly effective to see post disaster damages. The GPS coordinates converted into shape file and imported into ArcView software and these point then converted into polygons through field information (Figure-11 & 12). Each polygon is transformed into vulnerability class according to EMS. It is found that the totally collapsed buildings having zero shadows on the image, as the rooftop of the buildings is leveled with the floor, as result showing no or low shadows on this oblique image. With the help of supervised classification technique "zero shadow" areas were marked as training areas and a supervised classification algorithm has run, which finally gives the Figure-14. All zero shadows were isolated and enhanced in Figure-15 to represent a total picture of collapsed roofs. The results of the accuracy assessment of the shadow class is about 90% which could further enhanced if an original tiff image is acquired.

The ground information is also collected from the affected people and results are tabulated into Table-3, it was evident from the table that both public and private buildings were not ready to sustain the seismic shocks, people were not aware of any seismicity of the area and this earthquake was a total surprise for all of them.

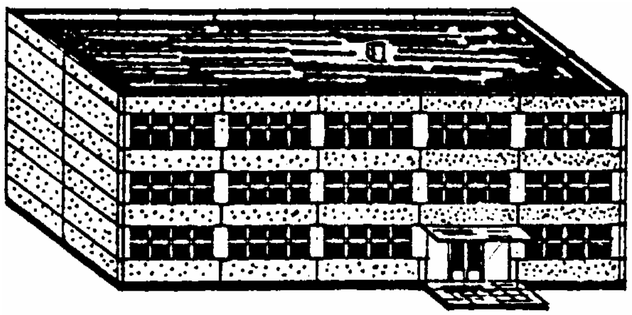
Table-2: European Macroseismic Scale

	Type of Structure	A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	●					
	adobe (earth brick)	●	—				
	simple stone	····	●				
	massive stone		—	●	····		
	unreinforced, with manufactured stone units	····	●	····			
	unreinforced, with RC floors		—	●	····		
	reinforced or confined			····	●	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	····	—	●	····		
	frame with moderate level of ERD		····	—	●	—	
	frame with high level of ERD			····	—	●	—
	walls without ERD		····	●	—		
	walls with moderate level of ERD			····	●	—	
	walls with high level of ERD				····	●	—
STEEL	steel structures			····	—	●	—
WOOD	timber structures		····	—	●	—	

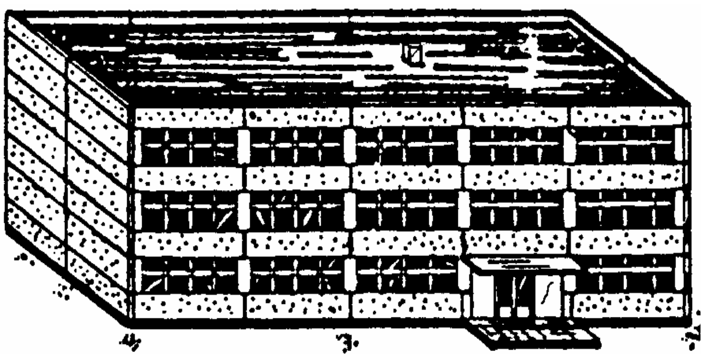
Vulnerability Class: A B C D E F

● most likely vulnerability class; — probable range;
···· range of less probable, exceptional cases

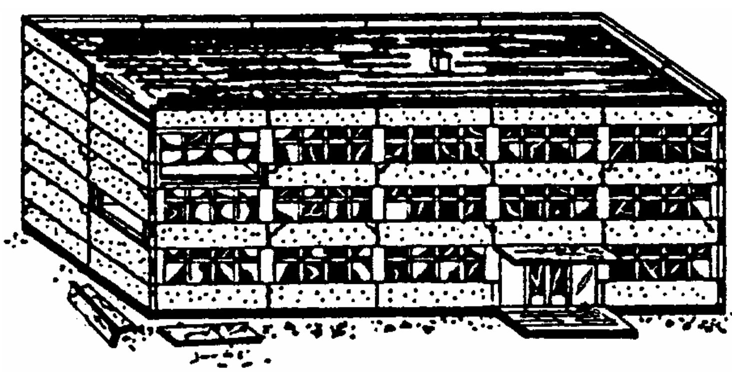
Source: (EMS, 2002)




Grade-1 (A)

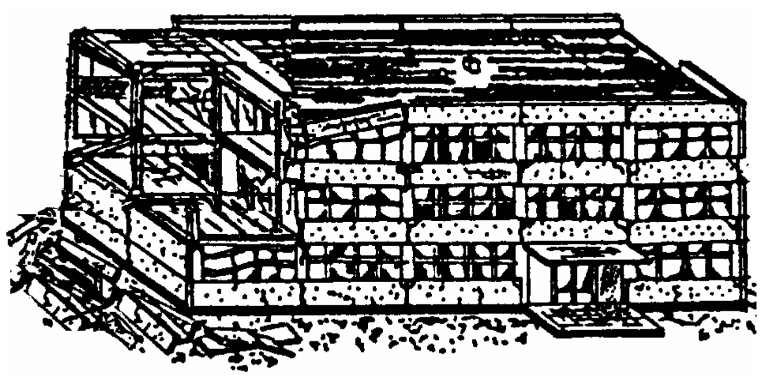



Grade-2 (B)




Grade-3 (C)

Figure-10; Continued…



Grade-4 (D)

Grade-5 (E)

Figure-10. ESA Code Illustrations and their Matches on the Ground in Garhi Habibullah *(See table-2 for Code details)*

Figure-11: Area surveyed is shown as the subset of the image.

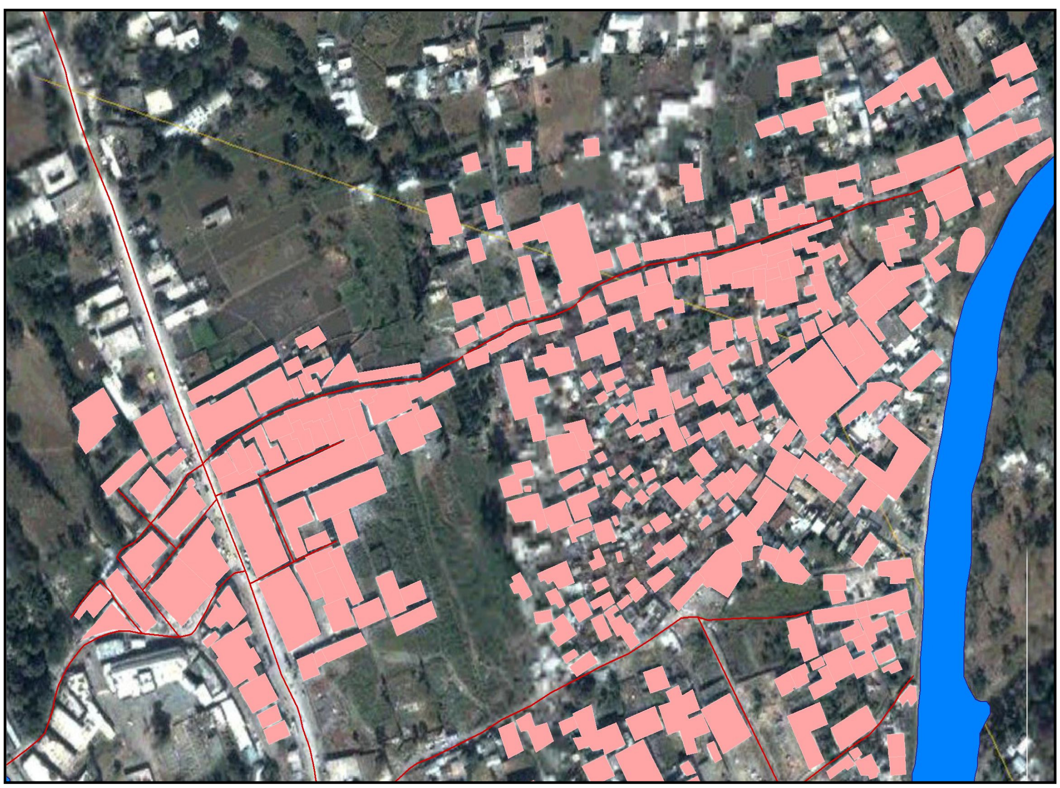


Figure-12: Surveyed Area is polygonized through on screen digitization and GPS coordinates.

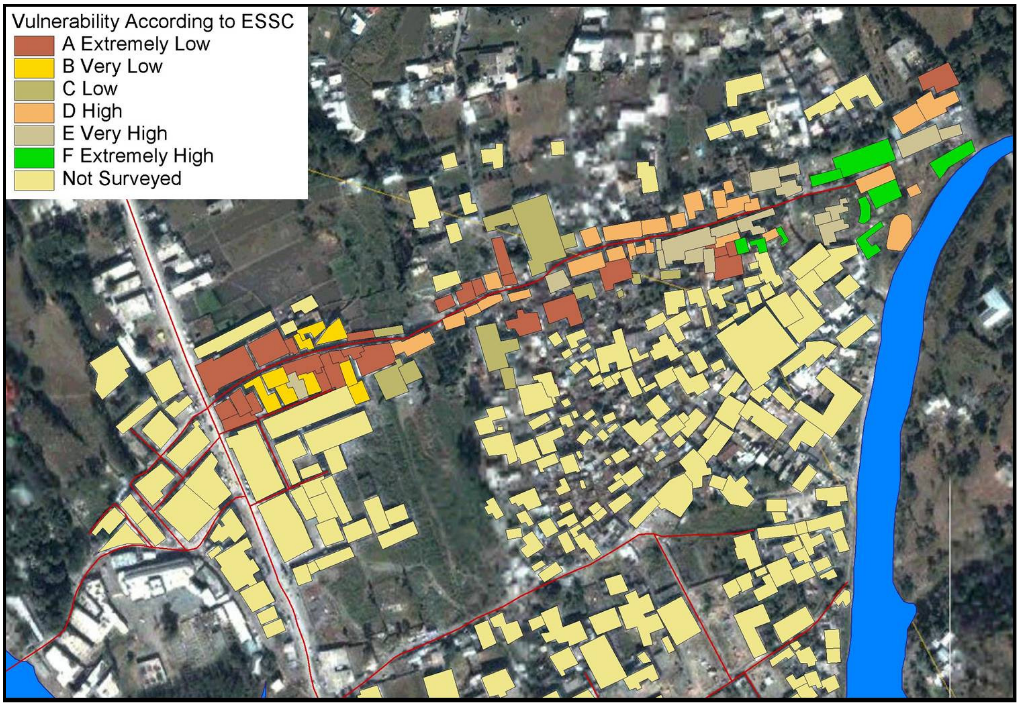


Figure-13: EMS Decoded Surveyed area in Garhi Habibullah transformed into Vulnerability Classes

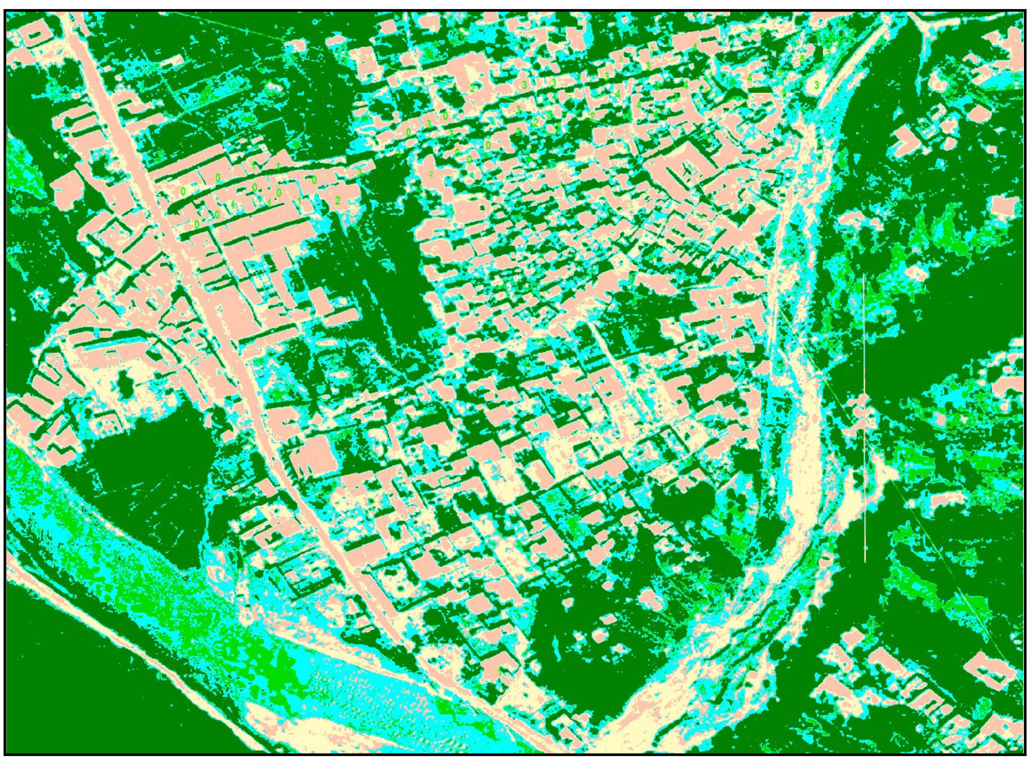


Figure-14: Thematic Classified Raster Layer to target zero Shadows

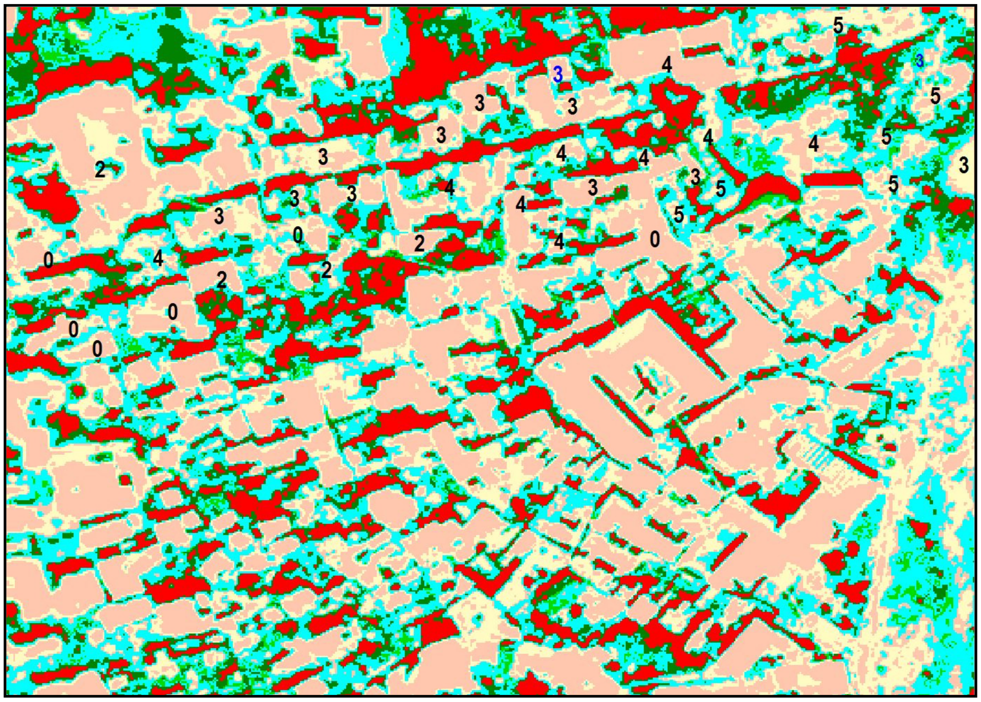


Figure-15: Enhanced Zero Shadows

Table-3. Affected Building types and Cause of Destruction by the local Respondents

Engineered (Government Buildings)	Non-Engineerined (Private Buildings/Homes)
Quality of constructions and construction materials	Lack of awareness about seismically resistant design
lack of seismic awareness	Sitting of structures
Lack of monitoring	Aspiration to modernize with sufficient knowledge of safe construction
Building Codes (Dichotomy)	Cost

Conclusions and Recommendations

This study clearly reveals the utility of remote sensing and GIS techniques in post earthquake damage assessment. Based on the USGS and GSP data of the last 100 years it is possible to interpolate the seismic points with the help of Inverse Distance Weighted (IDW) technique to develop seismic risks. It is obvious from this risk map that extremely high seismic areas are located in North East of NWFP and South and North West of Balochistan. The interpolated regions could further be defined with more accurate seismic stations data. From the visual interpretation of medium resolution imageries it is established that these imageries could be effective in marking landslides identification and would particular for relief and rescue operations. Landslides were a major secondary hazard due to the earthquake. The slides varied from major slides such as that seen in north of Muzaffarabad to disrupted slides, which pose a danger in future earthquake or during heavy rainfall. It was estimated through the satellite data that landslides may have occurred to a distance of about 200km from the epicenter. On the high resolution satellite data like IKONOS and QuickBird data it was evident to see the resulted damage to buildings and most notably lifelines (roads). This may have had an added impact on the casualties given the relative inaccessibility of many of the mountainous areas

From the field visit of Garhi Habibullah it is concluded that there is a substantial damage to the buildings in the area on the upslope of the mountains. A large proportion of damage occurred to residential structures. Commercial buildings, health care facilities, educational institutions and other government buildings also suffered severe damage. The idea to use GPS alongwith the EMS coding is an effective technique to develop large scale risk zone maps. Ground truthing could also provide a great help in interpreting features on the satellite imageries. The training areas which were marked on the satellite data have assisted to get finalize classified thematic map showing various classes of affected buildings. Supervised classification of the image provided outstanding results and we have been able to get the accurate results which were not surveyed during the field visit. This study is only of prelimnary type and with limited resources it is therefore recommended that an in-depth detailed seismic hazard assessment is carried out in the affected areas prior to the commencement of reconstruction. This study should be comprehensive and should incorporate the latest information like remote sensing and GIS to acquire data on geology, tectonics and seismicity in the area. A detailed seismic hazard assessment would allow the ground motion to be estimated in order to be used for seismic design and the evaluation of impact by secondary hazards such as landslides. It is advisable that a multi-hazard risk assessment is carried before selecting sites for reconstruction. The substantial damage to the buildings in the area suggests the lack of seismic resistant design and construction practice in the region. Therefore, author would like to recommend local indigenous techniques for the construction of the houses in the reconstruction phase which could be cost-effective and seismic resistant. In this regard Aga Khan University has developed a comprehensive document for the construction of houses through local material (Figure-16). It is therefore important that the reconstruction is carried out in accordance with proven seismic design methods given that the region is known to have sustained large earthquakes in the past. Given that a large proportion of buildings damaged were residential and hence their reconstruction will be primarily locally driven, there is need for a good education program in seismic resistant construction practices using local materials and local available technologies

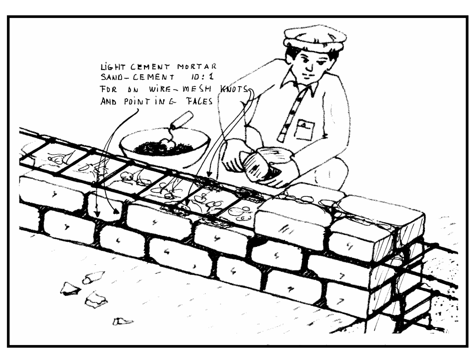


Figure-16. Indigenous Techniques of Field Stone and Adobe Masonry Developed by Aga Khan University

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