Title: Impact of 8th October 2005 Earthquake Associated with Kashmir Boundary Thrust (KBT), Pakistan

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Abstract: An earthquake on Richter scale of 7.6 intensity, originated from part of a fault zone more than 200 km long between Balakot and Reasi region of Jammu. This fault joins Indus Kohistan Seismic Zone (IKSZ). The epicenter was 11 km North - Northeast of Muzaffarabad while the depth was 15 km. The rupture zone along Kashmir Boundary Thrust was about 70 km in length. The area of impact is predominantly high relief with steep slopes, V-shaped valleys, and gorges. As a consequence of this seismic activity, about 70,000 people died while three-quarters of a million people were displaced. Most Govt. buildings including schools collapsed. Framework structures, wooden buildings and some buildings of NGOs built to withstand strong earthquakes in the area generally survived with minor damage. Communication networks collapsed disrupting rescue operations. Unavailability of helicopters in sufficient numbers, the absence of disaster management organization, lack of experience in rescue operations, and absence of locally available heavy machinery like lifts, cranes, bulldozers made the rescue extremely difficult resulting in very heavy losses. The government of Pakistan allocated 5 billion dollars for rehabilitation. However, the major contributor to the rehabilitation effort was Saudi Arabia. Physical changes (drying up of springs, temporary damming of streams, and increase in erosion) and ecosystem services destruction resulted due to this earthquake. Balakot city site located on rupture zone was very poor but situation was excellent since it was and even now is a hub of trade plus tourism for both Northern areas (GB) as well as Azad Jammu and Kashmir.

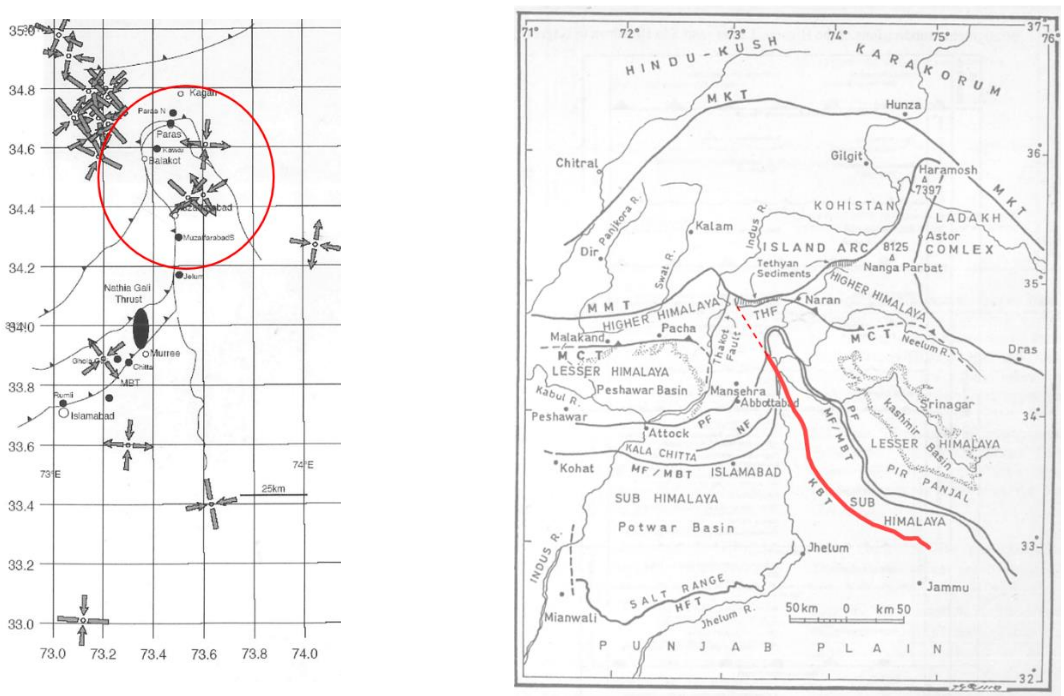
Keywords: Balakot, Environmental Impacts, Kashmir Boundary Thrust

Introduction

The devastating earthquake of 8th October 2005 which had a magnitude of 7.6 on the Richter scale had its epicenter at 34.4 °N, 73.5 °E, 12 km North West (NW) of Muzaffarabad (Ali et al., 2009). The focal depth of the earthquake was estimated variously between 15-25 km. The areas/cities which were subjected to severe shaking include the entire Hazara Division, Azad Kashmir, Indian held Kashmir, Kohistan, Northern Punjab, Northwest Frontier Provinces, and North Eastern Afghanistan (Baig, 2006). The most severely damaged town was Balakot, which was destroyed since it was located predominantly on Kashmir Boundary Thrust (KBT) rupture zone (Owen et al., 2008). The northern part of Muzaffarabad close to KBT was almost destroyed while parts of the city away from KBT suffered moderate damage. The city of Bagh suffered very heavily. The city was not located in a rupture zone but KBT passed close by as a blind fault, which daylighted within Murree formation. During the 8th October 2005, earthquake a discontinues rupture zone for about 70km (80 km according to Baig 2005) was observed (Baig, 2006). Rupture within Molassic Murree Formation close to the city of Bagh also appeared. Widespread damage occurred in Northern Hazara, and Kohistan due to the activation of the Indus Kohistan Seismic Zone following a rupture on KBT (Burg et al., 2005).

Geology: The area most adversely impacted by the 8^{th} October 2005 earthquake lies within and close to the well-known Syntaxis of the NW Himalaya (Wadia, 1931) known popularity as Hazara-Kashmir Syntaxis or HKS. Along this Syntaxis the 1500 km long E-W Himalayan strike bends suddenly making a hairpin bend folding Himalayan Megashear like Main Boundary Thrust (MBT) as well as a lesser megashear, the Panjal Fault (PT) (Figure 1).

This elongate domal structure with rocks younging towards the core is interpreted to have been formed by the piling of thrust sheets followed by the development of a domal structure (Greco, 1989). Parts of this fault zone have been variously designated in the order of their length, Muzaffarabad Fault (20 km), Balakot Bagh Fault (80 km), Kashmir Boundary Thrust (KBT) (undefined length). From Balakot through Buri Khel this fault is joined with Indus Kohistan Seismic Zone (IKSZ). The development of Syntaxis resulted in folding, reactivation of thrusts, and development of numerous imbricate zones. The area is replete with faults and imbricate zones. Subsequently, two major active faults developed i.e. Kashmir Boundary Thrust, KBT (Ghazanfar et al., 1986; Chaudhry & Ghazanfar, 1993) part of which was earlier mapped as Muzaffarabad Fault by Calkins et al. (1975) and a blind fault, the Indus-Kohistan Seismic Zone, IKSZ (Seeber et. al. 1979; Seeber & Armbruster, 1979).



a

b

Figure 1: (a)Map showing main fault location, epicenter and aftershocks in Balakot-Muzaffarabad areas (Burg et al., 2005).

HFT – Himalayan Frontal Thrust; **KBT** – Kashmir Boundary Thrust; **MCT**- Main Central Thrust; **MF/MBT**-Murree Fault/Main Boundary Thrust; **MMT** – Main Mantle Thrust; **MKT** – Main Karakoram Thrust; **NF**- Nathia Gali Fault; **PF** -Panjal Faut; **THF** -Trans Himadri Fault

The KBT is an upthrust structure that brings up Cambrian Dolomites through Miocene Muree Formation Molasse in Balakot, Garhi Habibullah, and Muzaffarabad. The KBT is a (partially blind) fault that brings up Cambrian Dolomites (Sirban Formation/Jammu limestone) through Miocene rocks once again near Kotli and Murree Formation and Siwaliks near Reasi in Indian occupied Kashmir. We propose that this fault continues for at least 200 km from Balakot to Reasi and therefore should be redesignated as Balakot-Reasi fault. The Reasi-Jammu Fault and the Muzaffarabad Fault are connected and designated as Kashmir Boundary Thrust (KBT) by Ghazanfar et al (1986). The Seismically active blind Indus Kohistan Seismic Zone (IKSZ) is connected with KBT via Buri Katha, Jabori and extends towards Batagram. The IKSZ-KBT together extend for almost 300km.

Seismicity: Main faults, epicenters, and aftershocks in and around the Syntaxial region are shown in Figure 1, and fault and stress analyses of the area are presented in Burg et al., (2005). The October 8th, 2005 earthquake had its epicenter at nearly the same place as the one NW of Muzaffarabad shown in Figure 2s. Since the faults are not monitored in Pakistan therefore little is known about the microseismic activity on these faults. The October 8th, 2005 Earthquake activated Indus Kohistan Seismic Zone. More than 1200 aftershocks were recorded within four weeks of the mainshock. While the epicenter was located on KBT, most of the aftershocks occurred along IKSZ. The IKSZ was reactivated immediately after the mainshock on KBT, 12 km NW of Muzaffarabad. The Jammu – Reasi section is the locked section of KBT which must have stored considerable stress and needs serious attention.

Socio-economic Impacts

Causes of Colossal Loss of Life and Property: In rural areas, the collapse of mud houses during the earthquake resulted in injuries and suffocation of the inmates. In villages and towns a large number of houses with walls built using rounded to subrounded cobbles (from nearby streams/terraces) and lean cement or mud paste collapsed like proverbial 'house of cards' killing or seriously injuring inmates in large numbers. A large number of these cobble lean paste/mud paste walled houses had heavy reinforced concrete roofs (lanter, which were built after people from AJK went to Middle East for Jobs). These roof slabs either killed or trapped inmates, many of whom died because they could not be rescued immediately due to lack of equipment (cranes, lifters, and reinforced concrete cutters). High-level terraces slumped and slides on peripheries resulting in the collapse and tumbling of houses. A large number of hamlets built on steep artificially terraced slopes were destroyed or buried due to extensive land sliding triggered by the earthquake. The inmates suffered very heavy casualties. The buildings, no matter how well built but sited on Kashmir Boundary Thrust active rupture zone, were destroyed.

Structures Demolition: According to EERI (Earthquake Engineering Research Institutes) the extensive damage was recorded in the areas of Muzaffarabad, Balakot, Bagh and Rawlakot. About 30-50% building infrastructure were completely damaged in the Muzaffarabad city according to EERI estimation. In the other cities (Anantnag, Baramula, Jammu, and Srinagar, Kashmir) ~32,335-780,000 buildings were collapsed (USGS, 2012; EERI 2006). Approximately 600 health facilities, 1,500- 17000 education buildings, water supply lines, roads, bridges, and other infrastructure were also destroyed in the country (Ross Hagan and Haroon Shuaib, 2014; EERI, 2006).

The Structures that Survived: Properly sited light all-wood structures/houses, and especially those with light slanting wood roofs, survived very well. There were very few casualties of the inmates. Concrete framework structured buildings with proper foundations survived very well. Some public utility buildings built, by International Organizations, NGOs, considering the seismic requirements of the area survived almost intact.

Rescue: The rescue phase did not go very well. The cost of lapses and delays at this stage resulted in many casualties. The reasons for this were as follows:

- The area is very rugged and landslide-prone with steep slopes and mass movements. It also has high levels of precipitation.
- The October 8, 2005 Earthquake triggered a very large number of landslides (Sudmeier-Rieux et al., 2011) (Figure 1a), some of which remained active for months and a few continue to move even today.
- This resulted in a total collapse of roads/paths, communication infrastructure, hampering land rescue efforts including the movement of rescue equipment, supplies, and personnel.
- Availability of very few helicopters, bad weather, narrow valleys, and the scale of destruction, limited very seriously the Heli-rescue operations. However, those injured who survived 48-72 hours were rescued by Pakistani helicopters followed by U.S. and German helicopters from Afghanistan.
- A most modern field hospital was established by U.S. to treat seriously injured patience.

- Government organizational structures in the areas affected by the earthquake completely collapsed due to very heavy casualties of functionaries and heavy destruction of Government built infrastructure. These structures were not built considering the seismic risks of the area. The Government personnel were killed or seriously injured while in their offices, workplaces, and on-duty sites. So, no authority could organize rescue immediately and systematically.
- There were no disaster relief cells/units and equipment in the area hit by October 8, 2005 earthquake.
- Unlike current excellent arrangements (by NDMA) there was no proper organization in the area to deal with natural disasters, nor was there any equipment or trained manpower to deal with earthquakes.
- There was no awareness at all in the masses about seismic risks and ways to deal with them.

Environmental Impacts

Air Pollution: Aerosols / Particulate matter Emission is one of the most reported air pollution-related to earthquakes. (Efstathioua, 2012; Hsu et al., 2010 and Okada et al, 2004). Major sources of air pollution in the area included landslides and the destruction of buildings. Air Pollution was widespread in areas where Murree Formation fluvial were exposed. The Miocene Murree Formation cyclic deposits contain thick beds of shale rich in clay. The aerosols keep suspended in the air for a long time. Dolomites belonging to the Abbottabad Formation of the Cambrian age pulverized on large scale between Muzaffarabad and Balakot producing particles of all sizes including aerosols. This resulted in widespread respiratory diseases as well as a few suffocation events (Aslam et al., 2020).

Methane Emission: The mismanagement of dead matter (trees, animals, and humans) and municipal solid waste can be the cause of methane emission which is a very portent greenhouse gas. According to Government figure approx. 250,000 farm animals died due to this earthquake. The sedimentary Paleocene and Eocene Package is known to contain source rock, reservoir rock, and cap rocks of hydrocarbons. The area has a number of active faults like Muzaffarabad Fault, Murree Fault (MF), Kashmir Boundary Thrust (KBT), Main Boundary Thrust (MBT), and imbricate zones. The tectonic events may release gaseous hydrocarbons(methane). No detailed studies were carried out however some reports of methane emissions were received.

Water Pollution: In the area, the problems in the water supply resulted in water pollution. In this zone, many overhead water tanks were damaged (Amin et al., 2009). Due to damage and pollution in river Neelum the municipal water supply was seriously affected (EERI 2006). Two small rivers at the bottom of valleys were also blocked due to the debris of the landslide created dam. Researchers reported a high level of contamination of *Escherichia coli* in drinking water after the earthquake due to the mismanagement of waste, vulnerable sewer system, and unhygienic conditions (Baig et al, 2005; Akbar et al, 2013).

Soil Pollution: The main sources of soil pollution included municipal solid waste (Dead Animals, animal waste, human waste, dead organic matter, etc.), Sewage (Domestic and Municipal), and Demolition Waste.

Ecological Disaster: A large Scale destruction of fauna (especially herpetofauna) and flora (including medicinal herbs) occurred due to land sliding. Subtropical scrub type vegetation at lower altitudes and temperate Himalayan mixed-forest through sub-alpine-scrub and alpine vegetation was heavily damaged along with rich herpetofauna. Drying up of springs, temporary damming of streams, increase in erosion especially gully erosion and sedimentation impacting the downstream Mangle dam. The tall pine-dominated forests prevail under semi-natural conditions. The area is diverse and is a hotspot, thus the earthquake had a severe impact on rare and significant wildlife species (Himalayan goral (*Naemorhedus goral*), different pheasants such as Cheer pheasant (*Catreus wallichii*), Lammergeier (*Gypaetus barbatus*), Lammergeier (*Gypaetus barbatus*), wild rabbits (*Lepus nigricollis)*, Western Horned-Tragopon (*Tragopan melanocephalus*), and foxes (*Pteropus giganteus))*.

Across the region, people rely directly on ecosystem services for their livelihood and sustenance, thus such mountain landscapes are highly vulnerable to changes in the ecosystem. Medicinal plants are an important source of income in the area that was destroyed during the earthquake. The natural hazards negatively impact the provisioning of ecosystem services. This relates to the already established literature that natural hazards (i.e. Earthquakes) are impacting agriculture and water services (Palomo, 2017). The tourism industry was impacted heavily after the earthquake.

Mitigation

This stage was a remarkable success. People from all over Pakistan, irrespective of caste, creed, religion, or nationality made huge financial and material contributions. The necessary supplies including tents, medicines, food, and clothing were generously transported to the earthquake-affected areas. Large quantities of supplies were also delivered to the official collection centers. Those who survived the earthquake in earthquake-hit areas generously helped their neighbors. After the earthquake, there was hardly any crime like stealing or looting. The government of Pakistan moved quickly and within a couple of weeks, opened most roads. Neelum valley road was so seriously destroyed that it took many weeks to open. In the first phase, the Pakistan Government and the International community provided tents medicines, doctors, food, hospitals, and temporary tent schools. In the second phase also Saudi Arabia was the major contributor. Prefabricated structures were provided for schools, colleges, hospitals, and other public utility buildings.

Rehabilitation

Pakistan Government allocated more than 5 billion dollars for rehabilitation. Most of the allocated money was provided by Saudi Arabia. Government buildings, especially schools, colleges, universities, and hospitals were rebuilt by 2012 using prefabricated hollow double steel sheets with insulators like polyurethane or thermopore. Outstanding examples of such structures were the University of Azad Jammu and Kashmir, Muzaffarabad & Hazara University. The people who lost their houses were provided cash compensation and training to build their own houses using prefabricated material and insulators (mainly thermopore). The above structures are all recyclable and could, be replaced by framework concrete structures or structures with approved earthquake-resistant designs and appropriate materials. Concurrent with the prefabricated structures more permanent structures approved for materials and design are being built. The rehabilitation activity has gone well.

Shifting of Balakot

A proposal was prepared to shift Balakot city to Bakrial granite hills (about 20 km south west of Balakot) with pine forest and not nearby active fault. Despite serious losses people did not shift because the site was good but situation was poor. People have settled in Balakot area since it is a trade and tourism hub.

Recommendations

Some recommendations are as follow.

- A federal Institute of seismotectonic studies should be established in Geological Survey of Pakistan.
- This Institute along with other related organizations dealing with seismotectonics should monitor all capable/active faults that pass close to or through cities, towns, and population clusters.
- Given October 8th, 2005 earthquake new and refined seismic zonation and corresponding building codes should be implemented.
- Fully equipped relief cells/units with trained manpower should be put in place to deal with natural disasters.
- All government and proposed disaster relief cells/units in calamity-prone areas must be housed in the very best earthquake-proof buildings.
- Construction should not be allowed on or close to rupture zones and fault splays.
- Construction should not be allowed in landslide-prone areas.

- Cobble-lean paste, mud paste structures, responsible for a large number of deaths, should be disallowed.
- Depending upon economic conditions, the following types of structures may be encouraged.
- Raft foundation combined with light wooden structure with fireproof treatment on the inside.
- Reinforced concrete frame structure with appropriate foundation design.
- Structures with raft foundation and a brick-mortar structure with reinforced concrete horizontal bands at plinth level, above doors/windows, and a reinforced concrete roof should be encouraged. The horizontal bands should be tied vertically to produce a braced structure.

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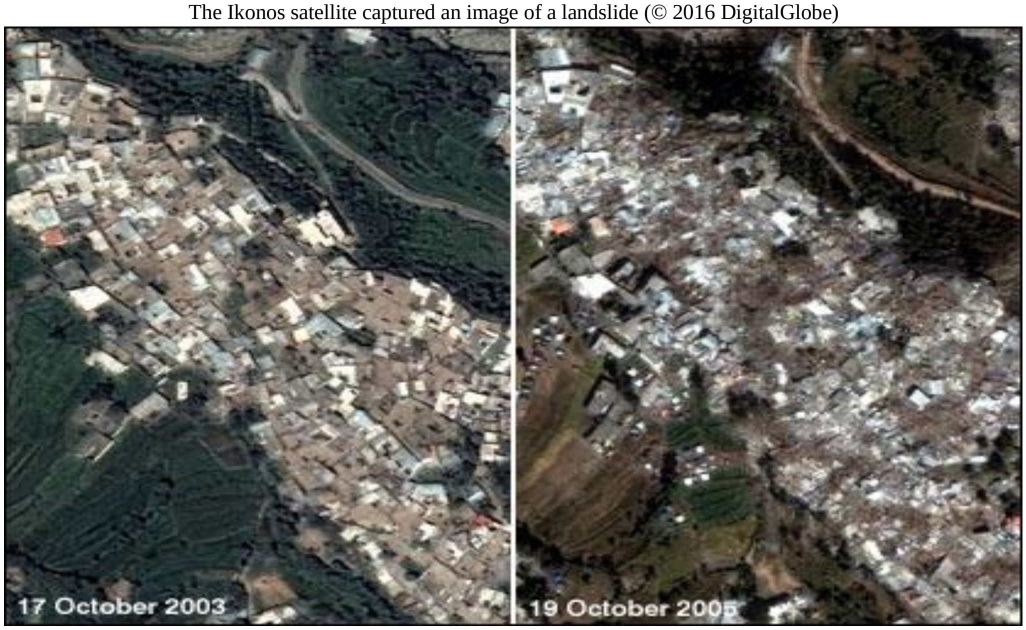
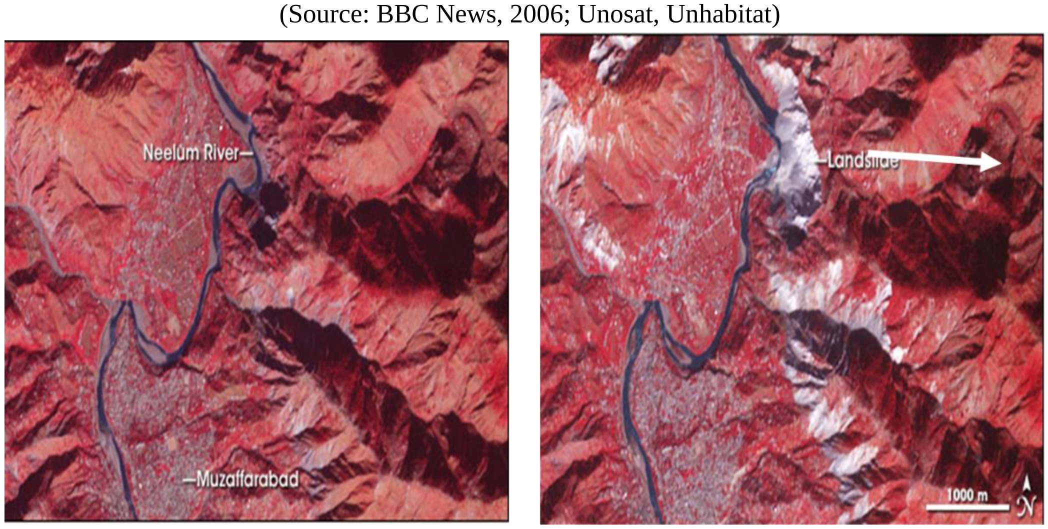
Supplementary Material

September 15, 2002 October 9, 2005

The Ikonos satellite captured an image of a landslide (© 2016 DigitalGlobe)

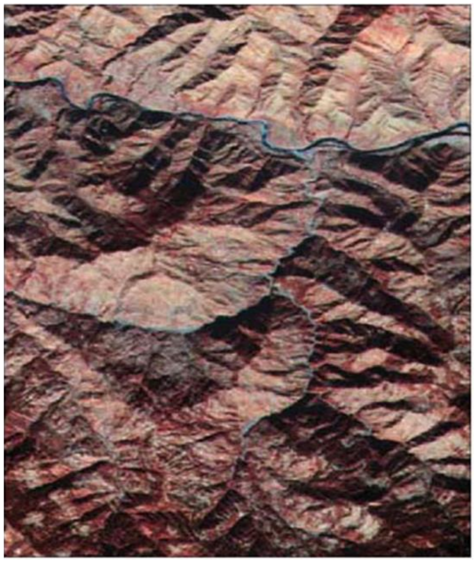


(Source: BBC News, 2006; Unosat, Unhabitat)



November 14, 2000 (*ASTER, VNIR (15 m)) (*NASA images by Robert Simmon)

October 27, 2005 (*ASTER, VNIR (15 m)) (*NASA images by Robert Simmon)



(a) November 14, 2000 (*ASTER, VNIR (15 m)*), (Avouac *et al.* 2006)

(b) October 27, 2005 (*ASTER, VNIR (15 m)*) (Avouac *et al.* 2006)

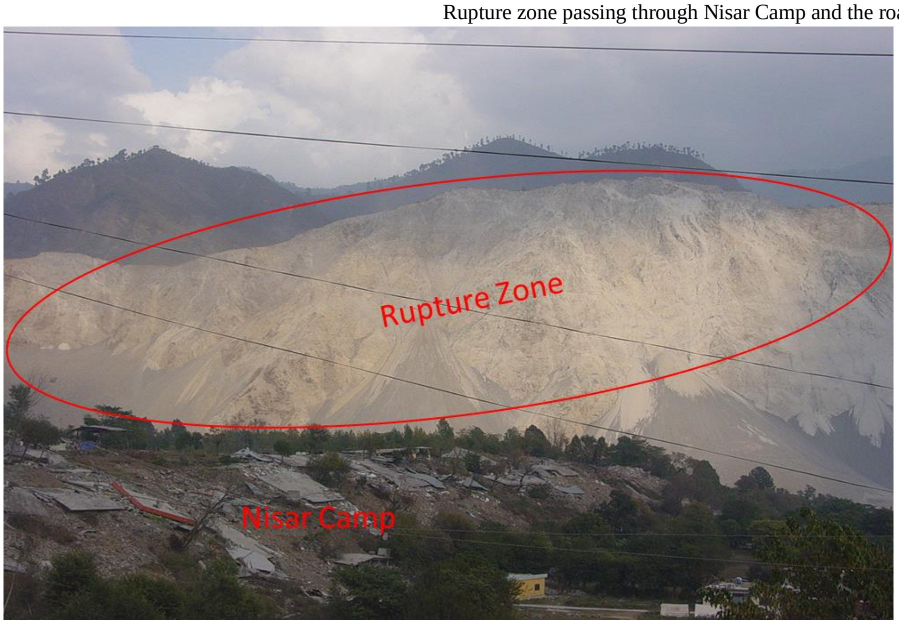
Figure 1s: Satellite images for visualization of the Balakot city and landslide of 8th October 2005

Active fault zone passing north of Muzaffarabad city

Rock sliding along a fault zone in Balakot area

Rock Fracturing on Balakot-Kaghan roadside

Rupture zone passing through Nisar Camp and the road site



Collapsed Nisar Camp, located near the active fault zone of Muzaffarabad

Destroyed Nisar Camp near Muzaffarabad close to rupturing zone

The lightweight wooden house proved earthquake-resistant compared to that constructed with blocks and improper shaped rock pieces-Dhirkot

Buildings constructed using cobbles and lean mortar suffer maximum damage –Bagh AJK

Fracturing and shaking caused major slides along the Kaghan road

Collapsed improper concrete buildings in the foreground and light wooden structures in the background

Slope failure caused damage to many buildings in Balakot

Devastated Old Campus of AJK University, Muzaffarabad

Slope/ soil failure in Muzaffarabad along with the River Neelam

Figure 2s: Visual illustration of some environmental impacts of 8th October 2005, Earthquake