CHAPTER 3

LANDSLIDE DISASTER MANAGEMENT

3. Landslide Disaster Management

3.1 General

This section describes the study results on the distribution of landslides (landslides and slope failures) and hazard assessment on landslides along the national road parallel to the Jhelum River (in ca. 255km^2) based on field inspections to the target area, visit to relevant agencies and review of past literatures and documents. The purpose the study is to provide appropriate basic materials for planning of practical measures for rehabilitation of the slopes along the national road. The contents of the study are as described below:

- **Preparation stage:** Acquisition of IKONOS images (monochrome stereo pair images with resolution of 1m), geological maps issued by the Geological Survey of Pakistan and available topographical maps. Creation of detailed topographical maps in scale of 1/25,000 using those basic data.
- **Topographical field inspections and recommendations of countermeasures:** Dispatch of experts on topographical analysis and planning of countermeasures. Field inspection of the representative landslides and grasp of topographical features on those landslide areas. Recommendation of countermeasures for recovery from the serious slope disasters caused by the earthquake.
- **Geological field inspections:** Dispatch of experts on engineering geology. Grasp of geological formations and structures. Analysis of the relationship between occurrence of landslides and geological conditions. Classification of types of landslides caused by the earthquake.
- **Hazard mapping on landslides (Preliminary Interpretation):** Preliminary detection of landslides using IKONOS images. Information on the distribution of landslides is to be utilized for training courses and seminars organized in Pakistan.
- **Examination of the method for hazard assessment on landslides (Joint Interpretation and the Analytical Hierarchy Method (hereafter AHP-Method)):** Joint interpretation of stereo pair aerial photos by experts on the target landslide. Selection of necessary factors (slope inclination, geology, geological structure, existence of undercut slope, clearness of landslide mass, existence of failure at toe part, etc.) for hazard assessment. Examination of the method for hazard assessment using AHP-Method etc. Results of hazard assessment are to be utilized for training courses and seminars organized in Pakistan.
- **Organization of training courses and seminars on hazard mapping and hazard assessment in Pakistan:** Organization of seminars in Islamabad. Presentation of

study results. Training to the engineers on interpretation technique of IKONOS stereo pair images and method for hazard assessment.

- **Digitalization of the results of the topographical interpretation on landslides by GIS:** Results of the topographical interpretation are to be digitalized using GIS software.
- **Preparation of a guideline of slope inspection for maintenance of roadside slope:** A practical guideline of slope inspection is prepared for maintenance of roadside slope.

3.2 Geomorphological Outline of Northern Pakistan

Indian subcontinent split from Gondwanaland had traveled northward since the Mesozoic era and finally sutured with Eurasia along a zone of Indus and Tsuampo Rivers in 50 Ma. The Himalayas have evolved as the gigantic arcuate mountains due to the continuous collision between Indian and Eurasian plates in the Cenozoic era. The Himalayas of two thousand kilometers long of E-W trend are fringed by the Buramaptra River at its eastern end and by the Indus River at its western end. The gigantic range turns its trend from E-W to the south at its both ends. They are named as the Patkai and Arakan-Yoma ranges in the east and as the Sulaiman and Kirtar ranges in the west. Those mountain system characterize the topographic outline of Indo-Eurasian collision zone (Figure 3.2.1)

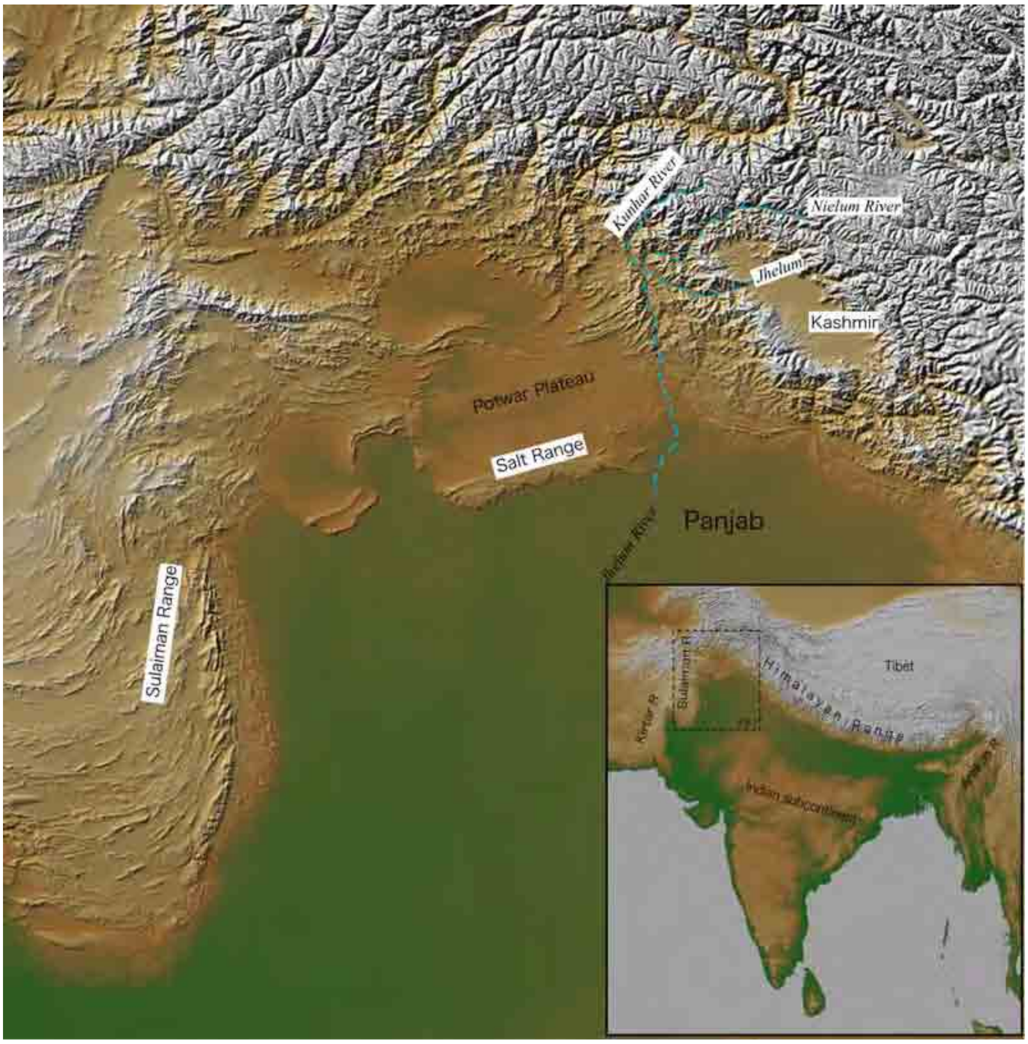


Figure 3.2.1 Geomorphological outline of northern Pakistan and its vicinity

(1) Topographic zoning in northern Pakistan

There develop three major tectonic lines in the northern Pakistan located in the western part of the Himalayas. They are the Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) respectively. They divide geomorphic zones in this area into three levels, the Lower Himalaya, Sub-Himalaya and Outer Himalaya (Figure 3.2.2). The Lower Himalaya ranges from 2000 to 4000 meters a.s.l., though the Nanga Parbad massif higher than 8000 meters due to plutonic upheaval is located at the great bend of the MMT just behind the Lower Himalaya. The Sub-Himalaya consists of Potwar Plateau and Salt Range of 500 – 1000 meters a.s.l. and the Outer Himalaya is Panjab plain below 300 meters a.s.l.

General trend of western part of the Himalayan Range is WNW-SES, however, mountain ranges of N-S trend along the Indus and Jhelum Rivers occur from the northern part of

Pakistan. This trend becomes more distinctive towards its southwestern continuation such as Sulaiman Ranges in the southwestern part of Pakistan. Thus, this area locates just at the bend of mountain ranges from E-W to N-S. This topography reflects complicated geological structure of the MBT, Hazara-Kashmir Syntaxis.

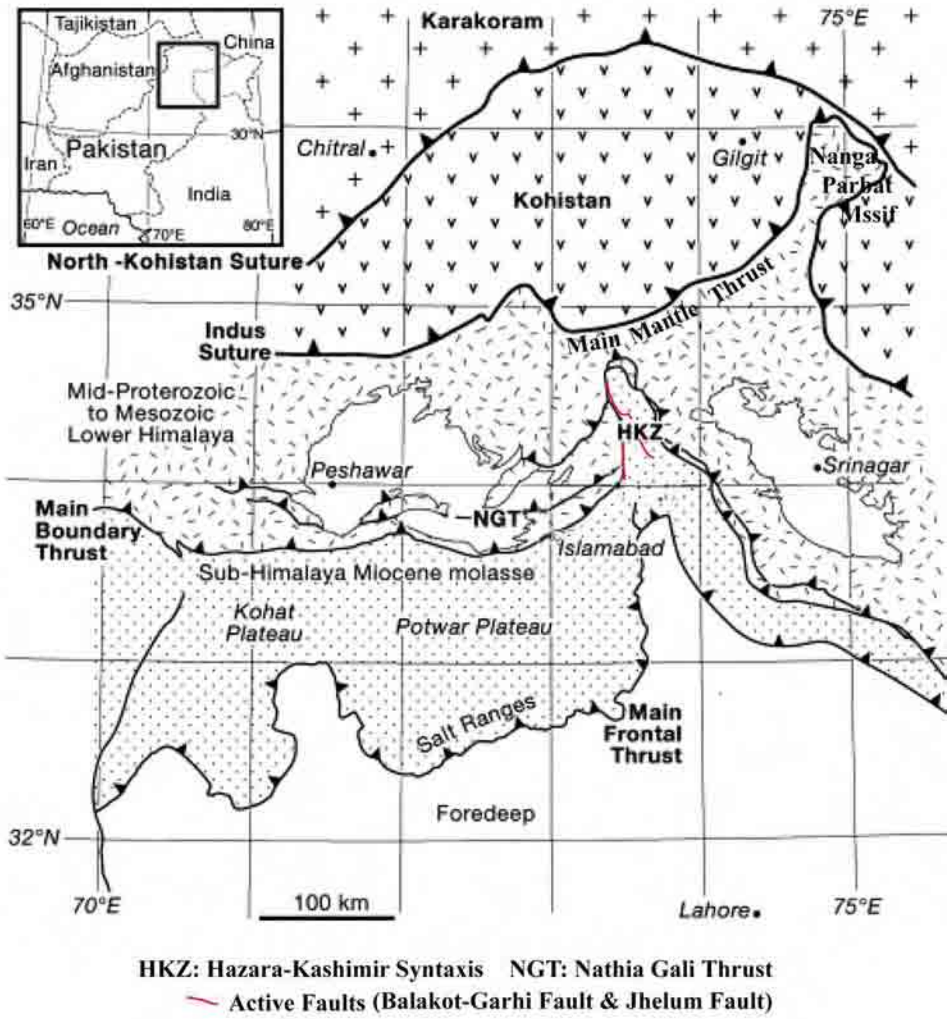


Figure 3.2.2 Geological & tectonic map of the northern part of Pakistan and its surrounding area after Burg et al,(2005)

The study area is located in the Lower Himalaya and its elevation is generally below 3000 meters a.s.l. (Figure 3.2.3). It consists of valley slope and floor of the Jhelum River. As mentioned above, trends of mountain ranges turn from WNW to N-S along the Jhelum River around Muzaffarabad.

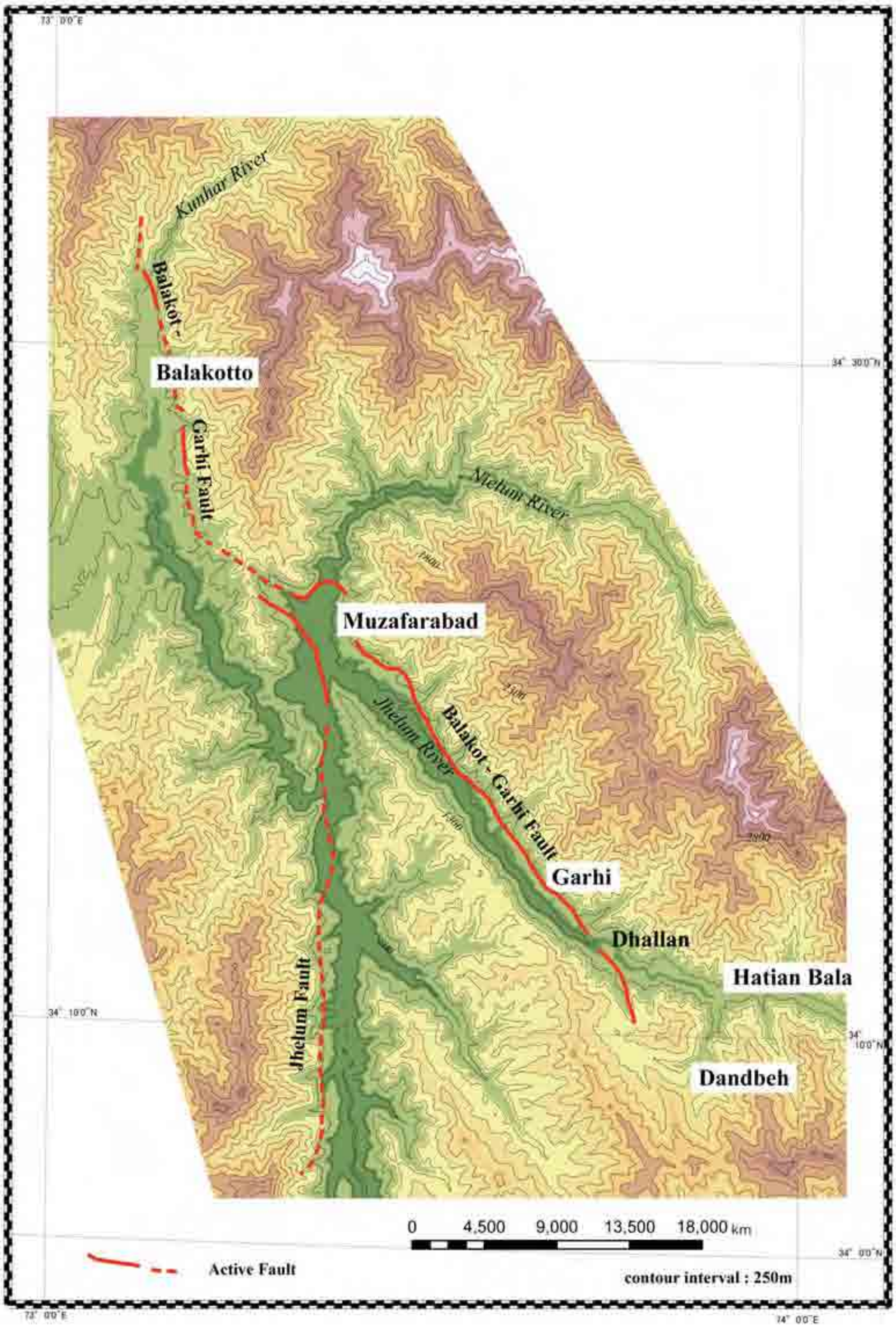
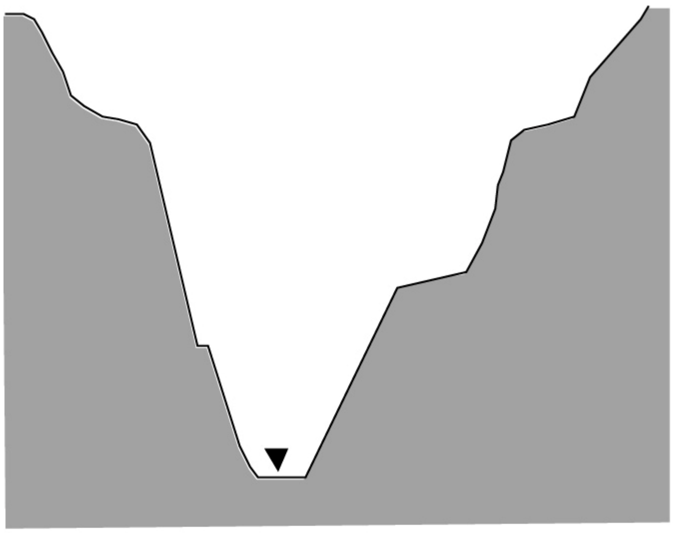


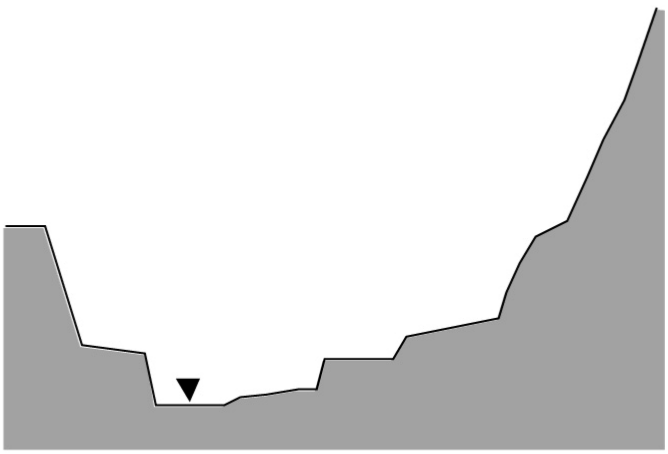
Figure 3.2.3 Topography in the vicinity of Jhelum,Nielum and Kunhar River watersheds around Muzaffarabad

Transversal profile of the Jhelum Valley shows two types. One is a wide valley floor type in the down stream from Naushana and another is a deep gorge type in the upper course from Naushana respectively (Figure 3.2.4). Such topographic variation is presumably caused by difference of expression of active faulting. The Ballakot - Garhi fault runs along the right bank of the Jhelum River from Muzaffarabad to Naushana and crosses the

Jhelum River to the left bank. It is a reverse fault with slight dextral component of which fault plain dips to northeast. Active faulting causes up-throw of the upstream side of the Jhelum Valley from Naushana. Consequently the up-thrown side inevitably undergoes subsequent river incision and forms a deep gorge, on the contrary, river floor is relatively stable in the lower course from Naushana, down-thrown area.



Valley profile along upper stream from Naushana



Valley profile along down stream from Naushana

Figure 3.2.4 Transverse profiles along the Jhelum Valley

Elevation of river floor increases from 600 to 800 meters a.s.l. along down-stream of the Jhelum River. River terraces develop along the right bank of the river in the down-stream side from Naushana, though steep valley slope of 40-70 degrees is only observed along its left bank. Such contrast in the valley profile is caused by much supply of detritus from northern watershed that is higher and wider than those in southern part. Low relief erosion surface remains at an elevation of about 1200 meters a.s.l. in the southern margin of the Jhelum Valley and wind gap has been formed as a paleo valley south of Garhi.

Elevation of river floor in the upper stream from Naushana ascends from 800 to 1000 meters a.s.l. The river terrace of the last glacial age develop as if it had once buried the Jhelum Valley, however, it has been incised deeply and the relative height from the river floor is about 100 meters. Lower river terraces of several levels are observed below the last glacial terrace.

(2) River system

Three major river systems flow in and around the study area (Fig.3.2.3). The Jhelum River comes from the Kashmir Valley in NE-NW trend to Muzaffarabad, running across the Hazara-Kashmir Syntaxis obliquely. It turns to the south, joining the Nielum River at Muzaffarabad. It conflows again the Kunhar river and flow southward along the MBT.

The Nielum River comes from southern flank of Nanga Parbat massif and flows to Muzaffarabad along the Hazara-Kashmir Syntaxis.

The Kunhar River flows in NNW-SSE trend via Balakot, forming a meander belt of zigzag in the west of Muzaffarabad where the Kunhar River intersects a zone of MBT. Trace of the Kunhar and Jhelum Rivers shows a step jog at Muzaffarabad.

(3) Active tectonics

The MBT dips north or northeastward in the northern part of this study area, however, it dips westward in its western part, bending its axis from E-W to N-S. Such syntaxis is named as the Hazara-Kashmir Syntaxis (Figure 3.2.2).

The Balakot-Garhi Fault is an earthquake fault that caused innumerable surface ruptures when the latest northern Pakistan earthquake in 2005 occurred (Photo 3.2.1). Surface rupture amounts to six meters occurred on alluvial terrace in case of the earthquake in 2005 (Kumahara & Nakata, 2005).

Photo 3.2.1 A series of tension cracks developed on a slope parallel to the active fault

General strike of the active fault is NW-SE. It occurs along the MBT as a western wing of the Hazara- Kashmir Syntaxis (Fig.3.2.2 and 3.2.3). However, the sense of active fault dipping to the east is adverse to that of the syntaxis dipping eastward. Trace of the Balakot-Garhi Fault shows a step jog at Chela, north of Muzaffarabad, forming a small scale syntaxis. And it continues southeastward along the piedmont line on the left bank of the Jhelum Valley from Muzaffarabad. It diverges from the west of Chela to the south crossing Muzafarabad city. It is the Jhelum Fault trending N-S and is southern continuation of the MBT along the Jhelum River. It is also an active fault, because it dislocates Pleistocene terrace in the south of Domei, forming east facing scarp (Photo.3.2.2).

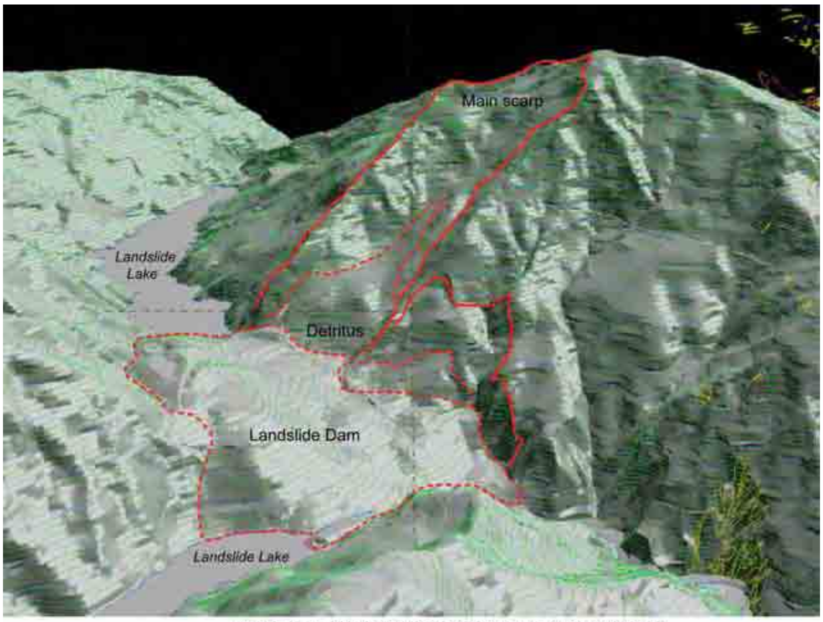
Photo 3.2.2 East facing active fault scarp of the Jhelum Faultsouth of Domei, Muzaffarabad

Northwestern part of the Balakot-Garhi Fault is located along a western wing of the Hazara-Kashmir Syntaxis. It, however, becomes independent from the MBT in the southeastern part from Muzaffarabad, and is marked by flexural scarps along the piedmont line on the right bank of the Jhelum River (Photo 3.2.3). The flexural scarps deformed fan surfaces formed by tributary rivers of the Jhelum River. Maximum displacement for the fan surfaces due to active faulting ranges 30-50 meters since the last glacial age. The fault line crosses the Jhelum River at Naushana and runs via Dhallan to enter to mountains near Chikar Kas.

Photo 3.2.3 Flexural scarp of the Balakot-Garhi Fault along the piedmont line on the right bank of the Jhelum River

(4) Landslides triggered by the 2005 Pakistan Earthquake

Numerous slope ruptures occurred accompanied by the earthquake. They are mainly described in chapter 3.5, however, typical and distinct landslides and slope failures at Dandbeh, Suguli, Bandi Tagian, Kuloli, BadiharaTotha, Dhallan, Naili and Jaskool are shown by virtual 3D bird's eye views created by combination of Quick Bird images and IKONOS's DEM data.



Bird's eye view of Dandbeh landslide and its vicinity from southeast

Bird's eye view from northeast

Figure 3.2.5 Dandbeh landslide as a catastrophic event triggered by the 2005 Pakistan Earthquake

Ridge slope of two thousand meters long with the relative height of eight hundred meters, max width of five hundred meters and max depth of fifty meters collapsed away near Dandbeh. This slope was located just above the syncline plunged to south, consequently it occurred as a rapid slide along a tilted gutter. Detritus of twenty five million cubic meters slid down and buried the Karrli Mala River, forming a landslide dam with the height of two hundred fifty meters

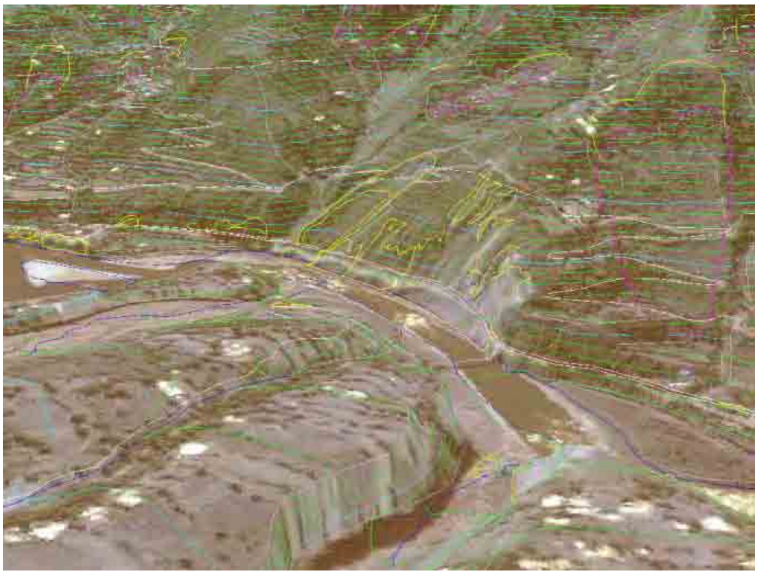


Figure 3.2.6 Slope failure marked by bare slope behind the barrage at Suguli where an under cut slope develops.

The Jhelum River flows from the left to the right in this picture. Deep landslide of activated one on the upper stream side of the slope failure also develops.

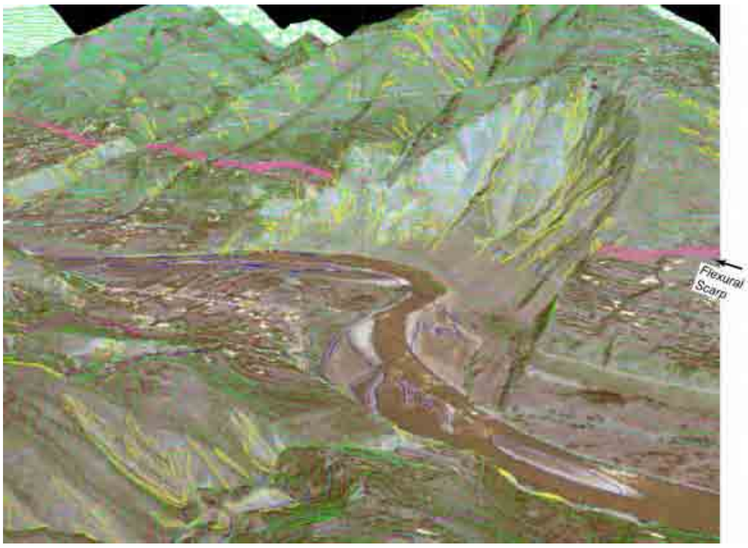


Figure 3.2.7 Slope failure of large scale at Bandi Tagian where an under cut slopes develops.

The Jhelum River flows from the righ to left in this picture. Balakot- Garhi fault as an active fault is located along the right bank of the Jhelum River. It forms flexural slopes on river terraces and also runs across the under cut slope.

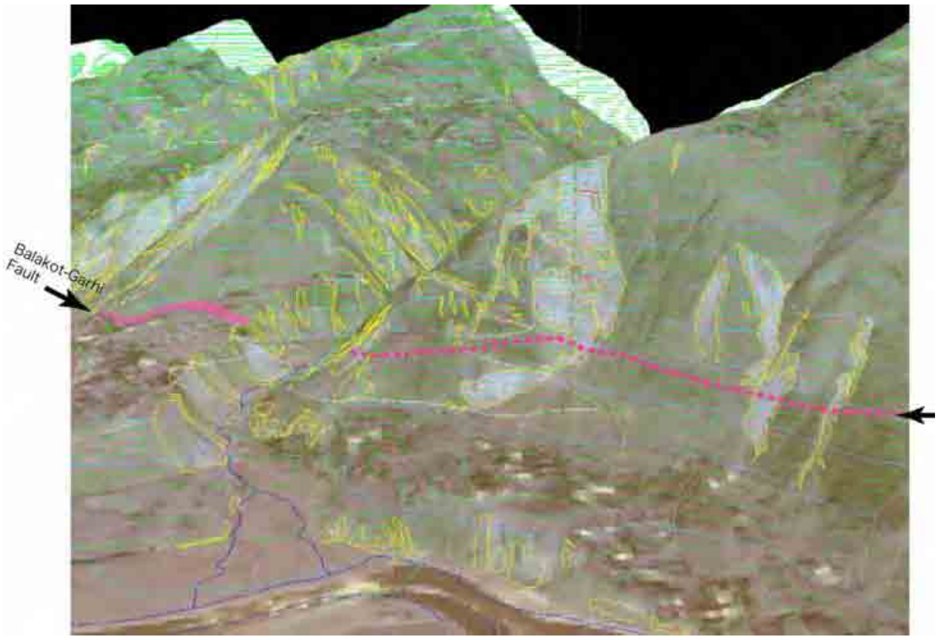


Figure 3.2.8 Slope failures of large scale at Kuloli where the active fault runs just along the foot slopes.

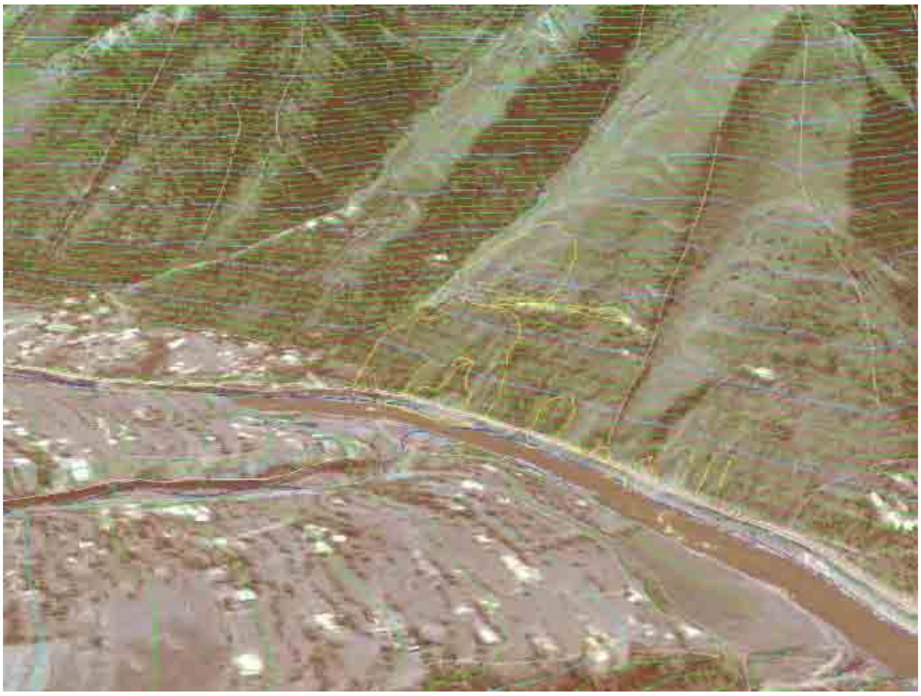


Figure 3.2.9 Deep active landslide of the initial stage at Badihara on an anti-dip slope in Muree Formation zone

The foot part of the landslide is undergoing sever toe erosion due to annual torrential stream of the Jhelum river. Besides the stream toe erosion, under cutting by civil road works against the toe part of the landslide facilitated to accelerate a rock landslide.

Figure 3.2.10 Flexural slope on the right bank of the Jhelum River around Totha downstream of Naushana

Numerable tension cracks parallel to the active fault are aligned on the flexural scarp. They are multi-genetic surface deformation combined with upheaval due to tectonic movement and subsequent gravitational movement. Some of them have expanded as slope failures.

Figure 3.2.11 Active landslides along the Jhelum valley road at Dhallan where Balakot-Garhi fault runs across it

Gradual slide has continued after the earthquake, deforming Jhelum valley road at Dhallan on the left bank of the river. They are also reactivated landslides because aerial photographs taken in 1978 show pre-existed scarps of landslide origin.

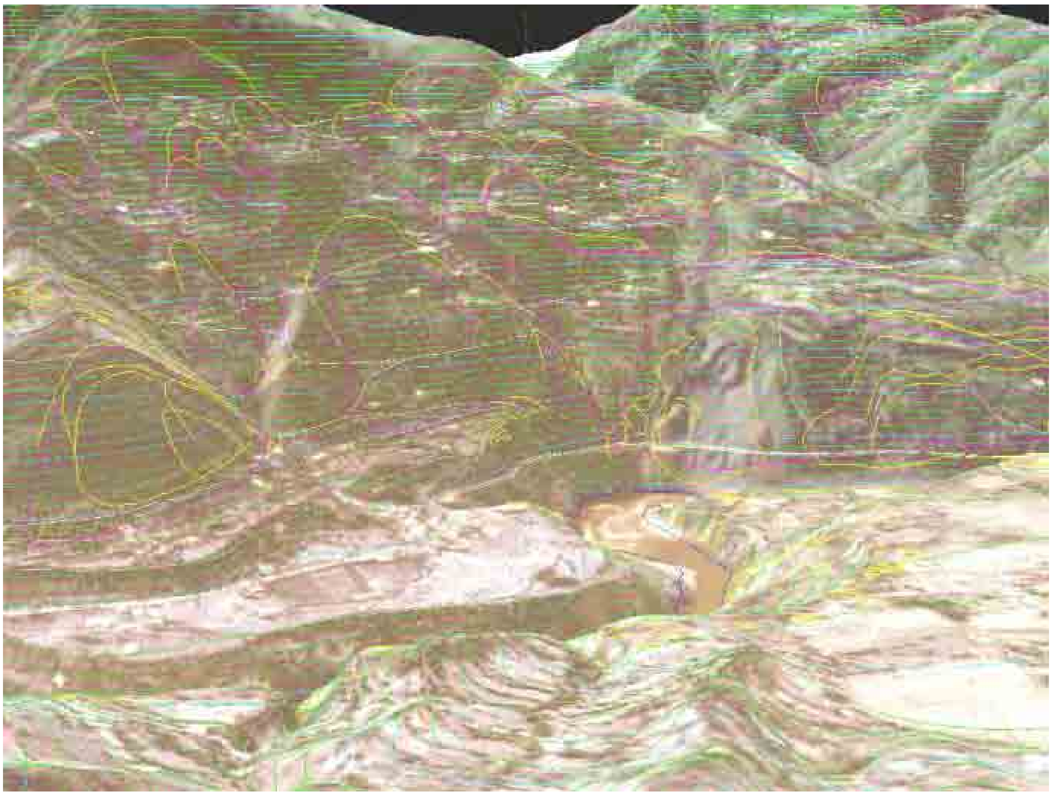
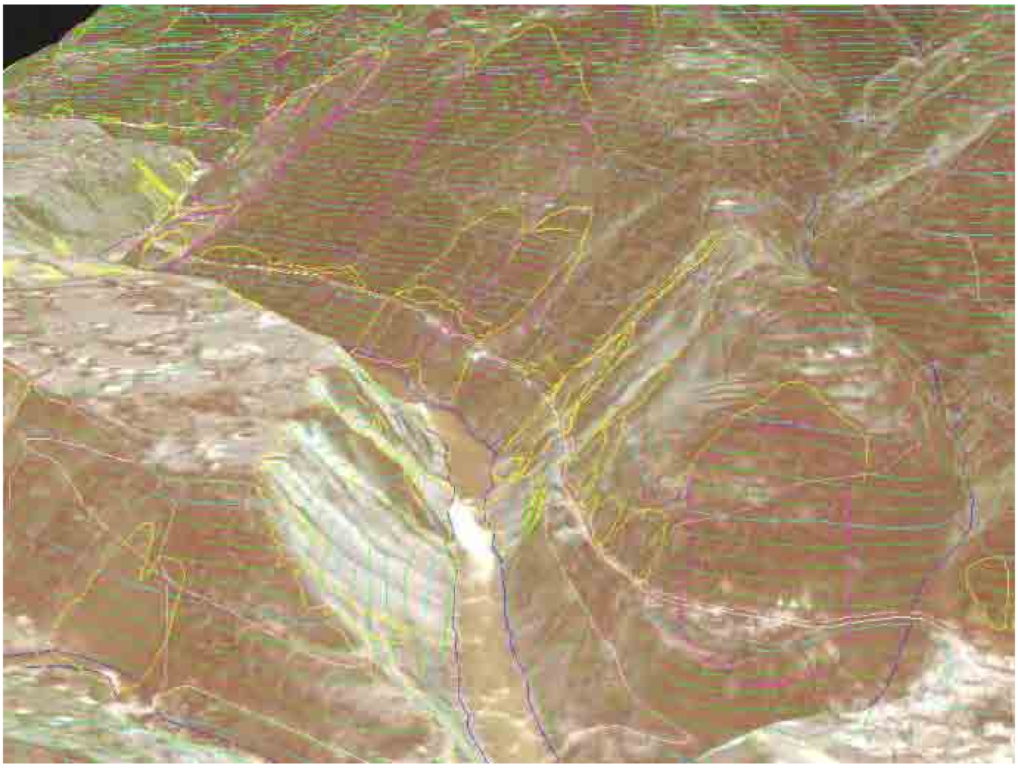


Figure 3.2.12 A series of deep and active landslides distributed at Naili along the gorge of the Jhelum River in the upper stream from Dhallan

This group of the Naili landslides is one of the most distinctive and problematic landslides in the valley. They are quite active, located on the under cut slope which has been undergoing sever toe erosion by the constant torrential stream of the river. Area of landslide covers a whole slope from the river bed to the ridge top for 700 - 1000 meters long.



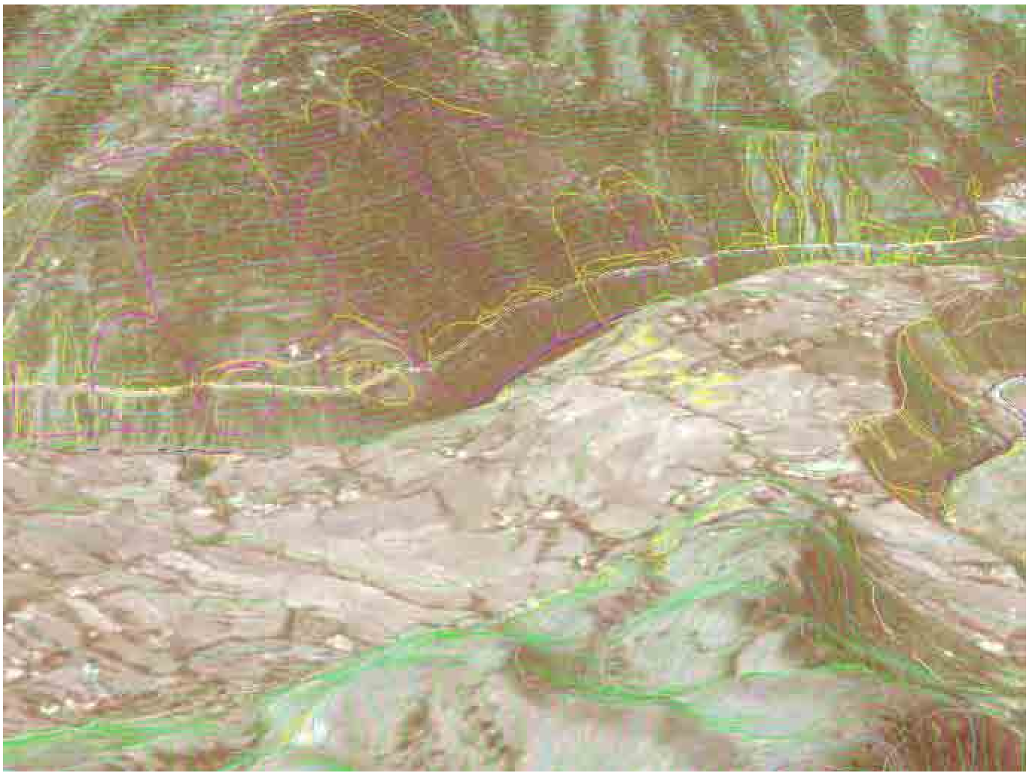


Figure 3.2.13 A series of Jaskool landslides as one of the active landslides

It undergoes sever toe erosion by the river and has a long slope behind that originates strong driving force.

3.3 Geological outline of northern Pakistan

The geological outline of this area is summarized from the description of Burg et al. (2003), and Kumahara and Nakata (2006). The following is the essence from these literatures.

The geological structure in the western Himalaya of Pakistan is characterized by north-dipping thrust belts as the past or present collision boundary between the Indian and Eurasian plates (Fig.3.3.1). The Indus Suture is the major northern boundary of the Indian Continent in the Western Himalaya of Pakistan. Two major structural units make the footwall of the suture: the Lesser Himalaya (on the north of the Main Boundary Thrust) and the Indian Foreland (also called Sub-Himalaya, on the south of the Main Boundary Thrust). Both are bounded by the Main Boundary Thrust. The Lesser Himalaya is a 20 km thick, imbricate thrust pile (a pile of sheets separated by thrusts) of mostly Middle Proterozoic to Mesozoic low-grade rocks. The Indian Foreland is a >10 km thick sequence of continental and shallow marine molasses sediments filling the flexural basin that developed along the southern front of the Himalayan Range. These sediments occur between the MBT and the Main Frontal Thrust (MFT, Himalayan Frontal Thrust in Fig. 3.3.1).

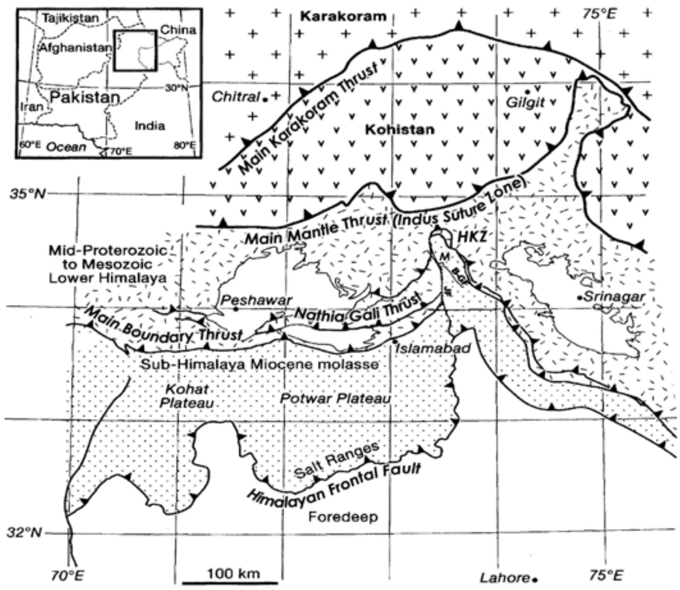


Figure 3.3.1 Tectonic map of the Western Himalaya. HKZ: Hazara-Kashmir Syntaxis; B-GF: Balakot-Garhi Fault; JF: Jhelum Fault; M: Muzaffarabad (From Kumahara and Nakata (2006), modified from Burg et al. (2005)).

The trace of the MBT protrudes northward sharply near Muzaffarabad and to the east of Islamabad. This is formed with a prominent and tight to isoclinal anticline in the sediments of the Sub-Himalaya. This is called the Hazara-Kashmir Syntaxis (Wadia, 1931) and is supposed to have been made by E-W compression. Within the north-ward protruded Sub-Himalaya exposed mainly the Miocene Murree and Kamlial Formations with local Muzaffarabad and Hazara Formations. These two are of Proterozoic in age. According to the legends of the geologic maps published by the Geological Survey of Pakistan, the Muzaffarabad Formation is a part of the basement of the Indian Shield uplifted by the fault. It consists of brown to dark gray, cherty, thin to thick bedded hard, rubbly and stromatolitic limestone and dolostone with a distinct carbonaceous limestone and shale horizon in the middle part. The Murree Formation consists of red purple and green sandstone, siltstone shale with subordinate intraformational conglomerate and lenses of limestone, indicating that the origin of the formation is non-marine fluvial environment. The Kamlial Formation overlies the Murree Formation and consists of purple gray and dark red, medium to coarse grained sandstone with interbeds of purple red mudstone and conglomerate.

The Murree and Kamlial Formations are folded with NW-SE trending axes. Particularly, the Murree Formation is intensively and tightly folded with wavelengths several to tens of meters. Flexural slip along the bedding planes develop during the folding. The Kamlial Formation occupies the axial part of a syncline running along the southwestern side of the Jhelum River. This syncline has a wavelength nearly 10 km.

The Balakot-Garhi Fault (Kumahara and Nakata, 2006) or Balakot-Bagh Fault (Kaneda et al., personal communication) appeared on the ground near and subparallel to the western rim of the Hazara-Kashmir Syntaxis. On a small-scale map (Fig. 2.2), the northern part of the Balakot-Garhi Fault seems to extend along the western rim of the Hazara-Kashmir Syntaxis, but in the northern part of the Balakot-Garhi Fault trace does not exactly follow it. Southeastern part of the Balakot-Garhi Fault appeared along the Jhelum River within the Sub-Himalaya.

References:

Burg, J., -P. Célérier B., Chaudhry, N.M., Ghazanfar, M., Gnehm, F., and Schnellmann, M. (2005): Fault analysis and paleostress evolution in large strain regions: methodological and geological discussion of the southeastern Himalayan fold-and-thrust belt in Pakistan. Journal of Asian Earth Sciences, 24, 445-467.

Kumahara, Y. and Nakata, T. (2006): Active faults in the epicentral area of the 2005 Pakistan earthquake. Special Publication no. 41, Research Center for Regional Geography, Hiroshima University, 54p.

Wadia, D.N. (1931): The syntaxis of the north-west Himalaya-its rocks, tectonics, and orogeny. Records of the Geological Survey of India 65 (2), 189-220. In Burg et al. (2005).

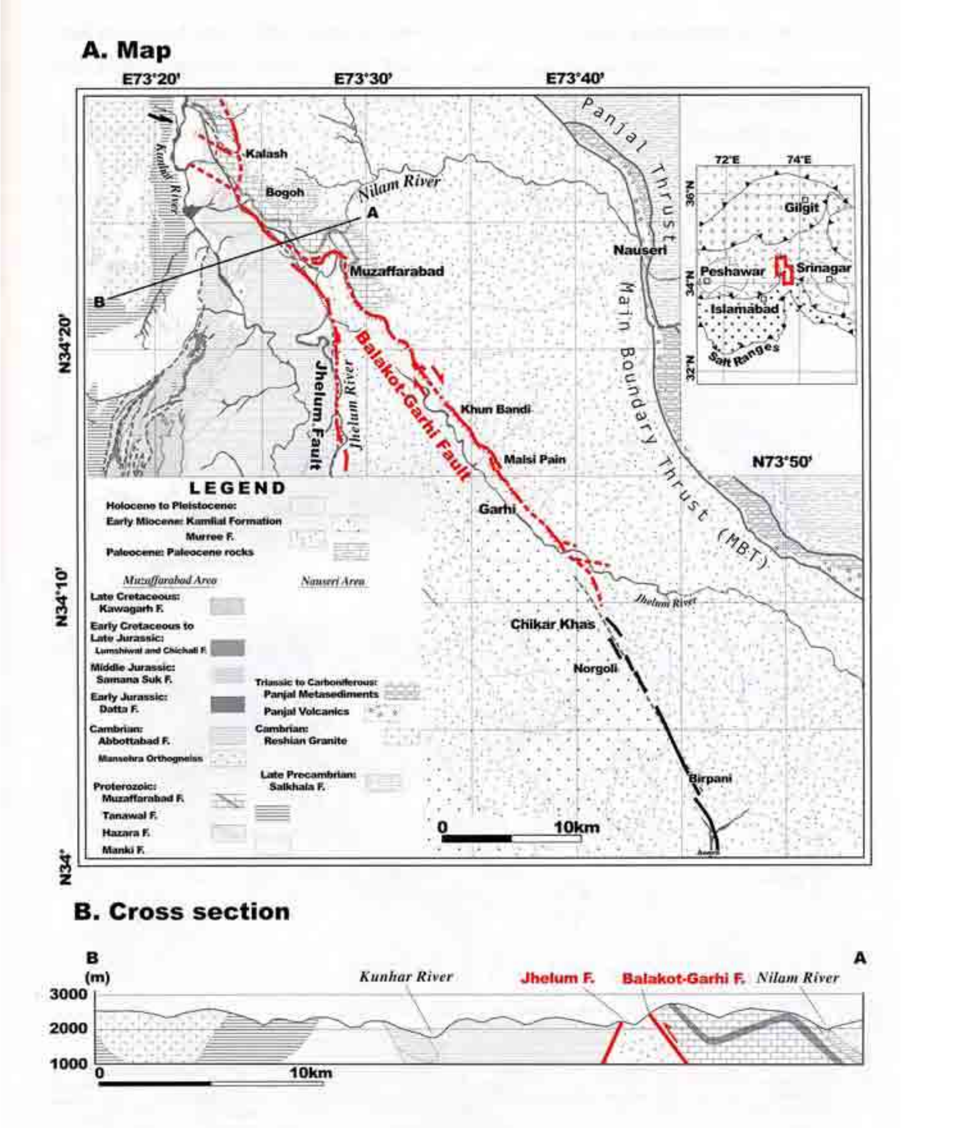


Figure 3.3.2 Geology of the epicentral area with the Balakot-Garhi fault. From Kumahara and Nakata (2006). Compile map of 1:50,000 Geological Map Series Vol. VI, No. 13, 14, 16, and 17 published by the Geological Survey of Pakistan.

3.4 The 2005 Northern Pakistan Earthquake

The outline of the 2005 northern Pakistan Earthquake (Figure 3.4.1, 3.4.2 and 3.4.3) (http://earthquake.usgs.gov/eqcenter/eqinthenews/2005/usdyae/#details)

Magnitude: Mw7.6

Date:

Saturday, October 8, 2005 at 03:50:40 (UTC, Coordinated Universal Time)

Saturday, October 8, 2005 at 8:50:40 AM (Local Time)

Location: 34.493°N, 73.629°E

Depth: 26 km

Location: 105 km (65 miles) NNE of ISLAMABAD

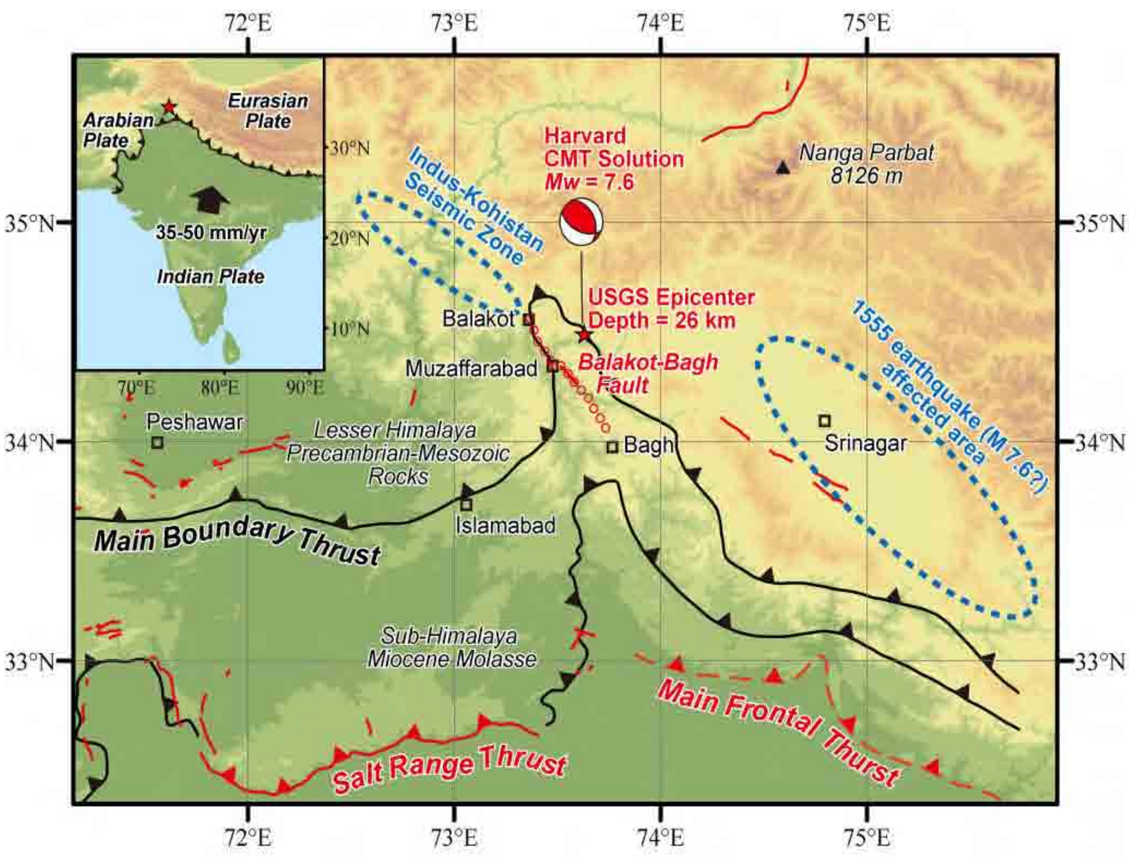


Figure 3.4.1 Tectonic map and the location of the epicenter (Kausar et al., 2006).

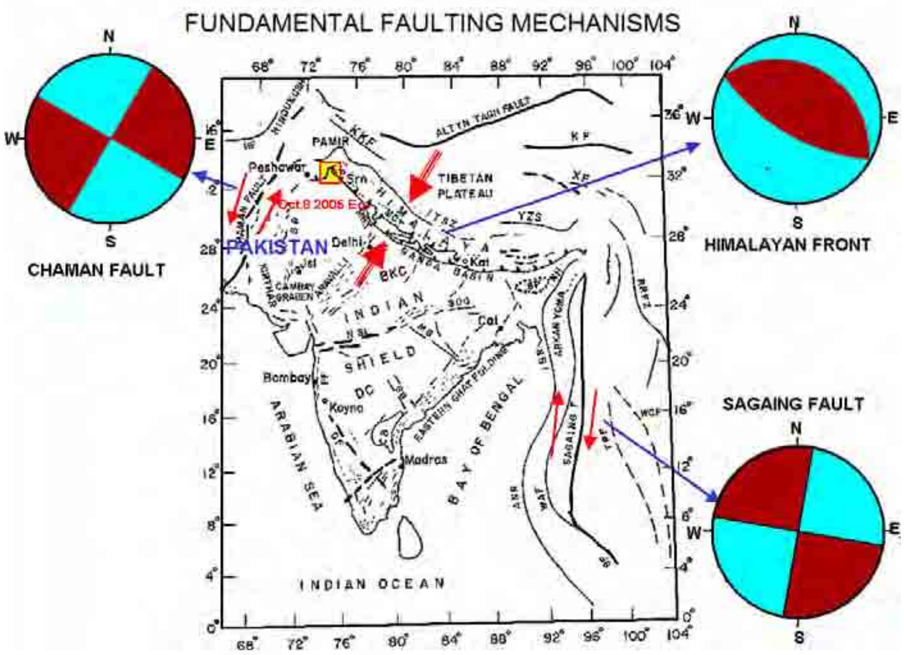


Fig.3.4.2 Location of the epicenter in the regional tectonic framework. (Kausar, et al., 2006). Himalaya Front: Thrust； Chaman Fault: Sinistral； Sagaing Fault: Dextral

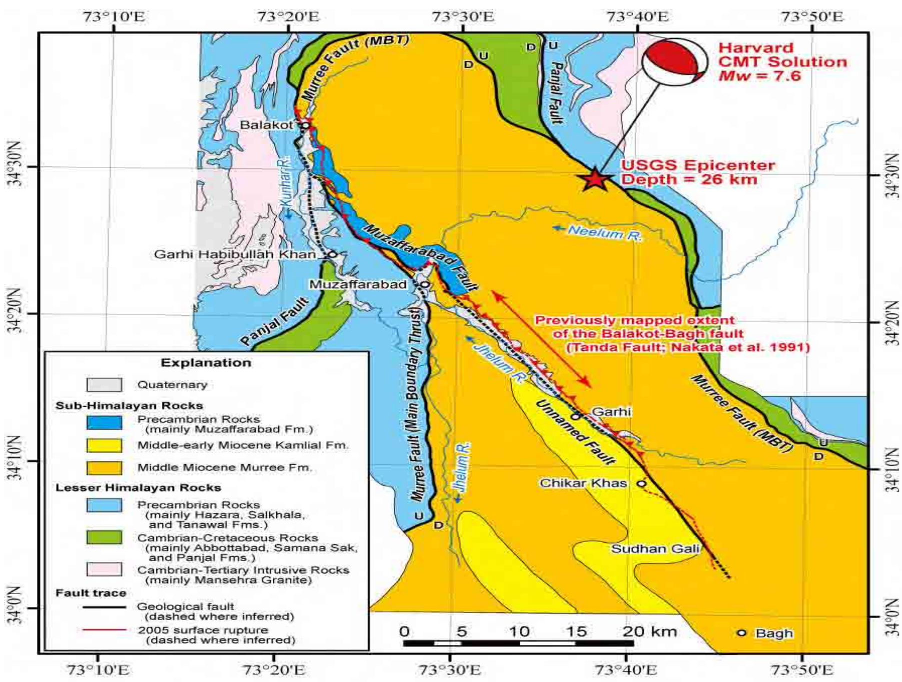
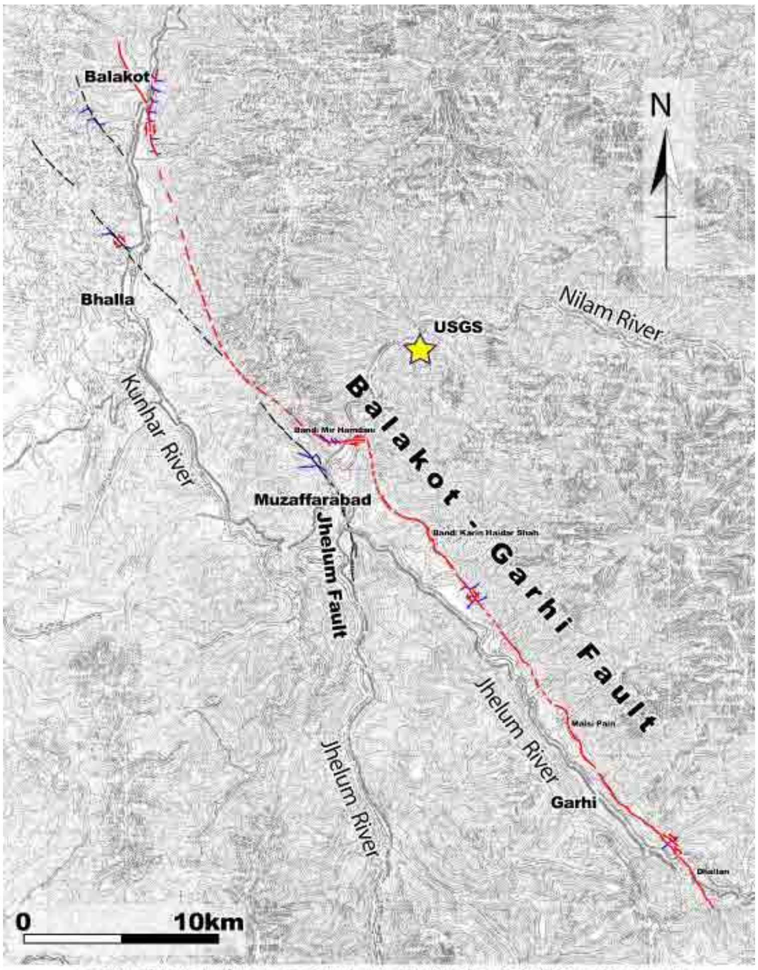


Figure 3.4.3 Geologic map and the location of the Tanda Fault and the epicenter (Kausar, et al., 2006)



Location of the active faults in the source area of the October 8, 2005 Pakistan Earthquake
Red lines: Active fault traces reactivated on October 8, 2005earthquake
Black lines: Active fault trace unmoved on October 8, 2005earthquake
Combs indicate down-thrown side along the faults. Arrows indicate direction of strike-slip.
Blue lines crossing the fault trace indicate offset of stream.
Base map was published by the former Soviet Union.

Fig.3.4.4 Location of active faults and reactivated active fault (red line). From the Geological Survey of Japan web site (http://unit.aist.go.jp/actfault/katsudo/jishin/pakistan/fig.01.html).

(Reactivated fault)

Nakata et al. (1991) mapped active faults in Pakistan by air-photo interpretation, and identified the Tanda Fault along the Jhelum River. Just after the 2005 earthquake Kumahara and Nakata recognized that the Tanda fault extends further northwestward. The Japanese-Pakistan Joint Team revealed that surface fault rupture appeared along the active fault trace they mapped (Figure 3.4.4, Geological Survey of Japan, 2005;

http://unit.aist.go.jp/actfault/katsudo/jishin/pakistan/fig.01.html; Kumahara and Nakata, 2006). The fault was NW-SE trending reverse fault with upheaval of the north side by a maximum vertical displacement of 5.5 m.

Tobita et al.(2005) analyzed the In-SAR data obtained by ENVISAT and obtained an image of ground surface displacement (Figure 3.4.5), in which the displacement occurred just along the active fault shown by Nakata and Kumahara (2005), and the northeastern side of the fault upheaved up to about 6 m.

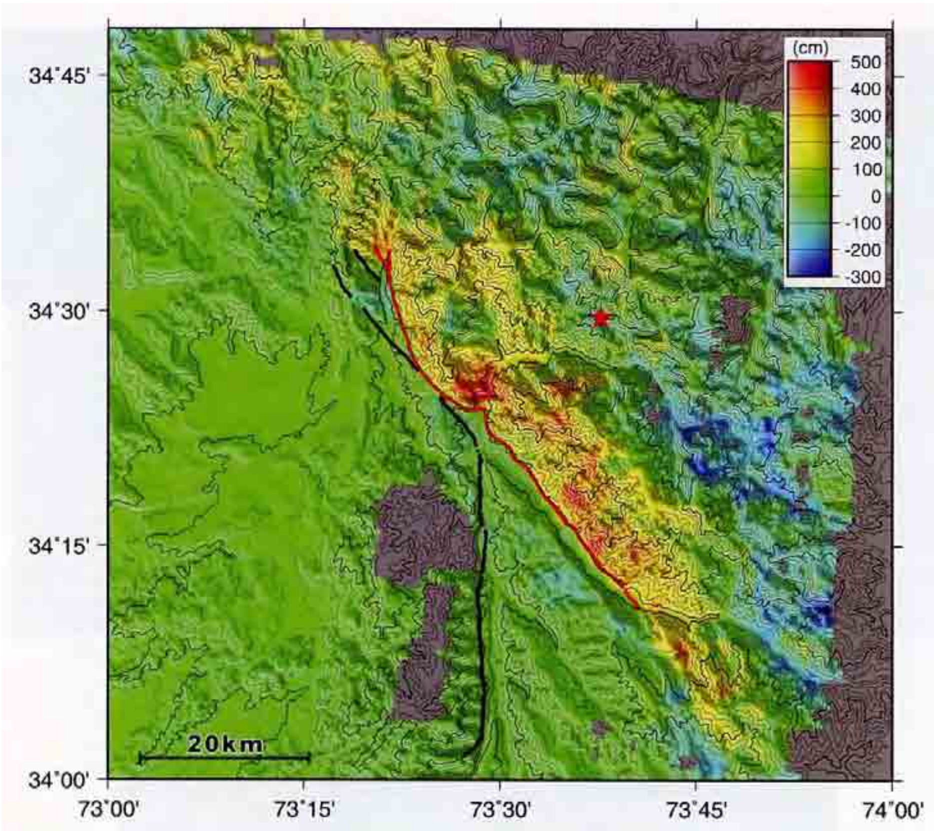


Fig.3.4.5 Coseismic crustal deformation of the 2005 Northern Pakistan earthquake by SAR image matching with the fault trace (Kumahara and Nakata (2006) modified Fujiwara et al. (2006)).

Seismological analysis by the USGS indicated NW-SE-trending reverse fault

(http://earthquake.usgs.gov/eqcenter/eqinthenews/2005/usdyae/#scitech)

(Damage)

From the web site of the USGS, the damage occurred is as follows.

At least 86,000 people were killed, more than 69,000 injured and extensive damage occurred in northern Pakistan. The heaviest damage occurred in the Muzaffarabad area, Kashmir where entire villages were destroyed and at Uri where 80 percent of the town was destroyed. At least 32,335 buildings collapsed in Anantnag, Baramula, Jammu and Srinagar, Kashmir. Buildings collapsed in Abbottabad, Gujranwala, Gujrat, Islamabad, Lahore and Rawalpindi, Pakistan.

Maximum intensity was VIII at Muzaffarabad (Figure 3.4.6). Felt (VII) at Topi; (VI) at Islamabad, Peshawar and Rawalpindi; (V) at Faisalabad and Lahore. Felt at Chakwal, Jhang,Sargodha and as far as Quetta. At least 1,350 people were killed and 6,266 injured in India. Felt (V) at Chandigarh and New Delhi; (IV) at Delhi and Gurgaon, India. Felt in Gujarat, Haryana, Himachal Pradesh, Madhya Pradesh, Punjab, Rajasthan, Uttaranchal and Uttar Pradesh, India. At least one person was killed and some buildings were collapsed in Afghanistan. Felt (IV) at Kabul and (III) at Bagrami, Afghanistan. An estimated 4 million people in the area left homeless.

Landslides and rockfalls damaged or destroyed several mountain roads and highways cutting off access to the region for several days. Landslides occurred farther north near the towns of Gilgit and Skardu, Kashmir. Liquefaction and sandblows occurred in the western part of Vale of Kashmir and near Jammu. Landslides and rockfalls also occurred in parts of Himachal Pradesh, India. Seiches were observed in Haryana, Uttar Pradesh and West Bengal, India and many places in Bangladesh.

Landslides were concentrated along the Balakot-Garhi Fault, particularly on the hanging wall slopes of the northwestern half of the fault trace. This seems due to the hanging walls consist of Precambrian limestone there. On the other hand, along the southeastern half of the fault trace in the Miocene Murree Formation, landslides were not concentrated just along the fault trace. The Murree Formation consists of hard sandstone and ductile mudstone, so earthquake tremor might have become weak at the slope surface and landslides did not concentrate along the fault trace. Limestone on the other hand, is hard and not ductile, so earthquake tremor might not have become weak on the slope surface and surface loosened limestone blocks might have collided to each other and failed.

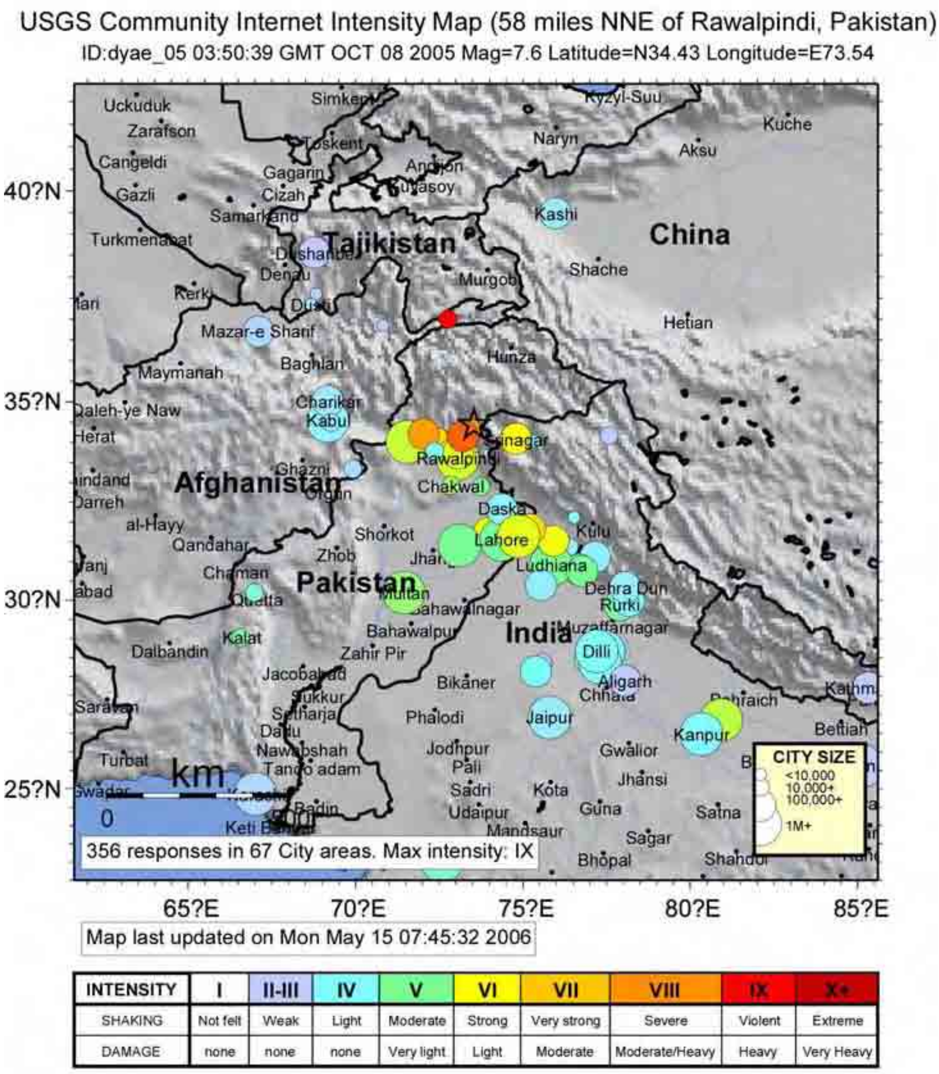


Fig.3.4.6 Intensity map of the 2005 Northern Pakistan Earthquake (from the web site of USGS, http://earthquake.usgs.gov/eqcenter/eqinthenews/2005/usdyae/#maps). Intensity VIII is recorded in Muzaffarabad, and Srinagar and Rawalpindi VI.

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U.S. Geological Survey web site:

(http://earthquake.usgs.gov/eqcenter/eqinthenews/2005/usdyae/#details) accessed on 16, January, 2007.

3.5 Landslides and slope failures triggered by the 2005 Northern Pakistan Earthquake

(1) General

All landslides and slope failures triggered by the 2005 Northern Pakistan Earthquake were delineated by interpretation of aerial and satellite images to recognize the slope disasters in the Jhelum Valley. Landslides that we call here are defined as deep landslides of which sliding surface are situated deeply (Photo.3.5.1) and moving materials often remain on the mid slope (Figure 3.5.1).

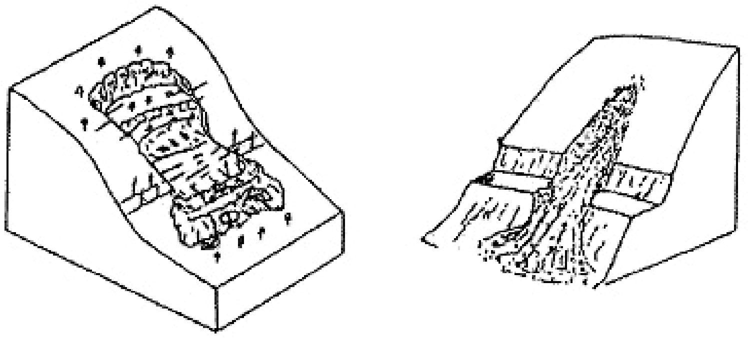


Figure 3.5.1 Definition of landslide and slope failure (Higaki et. al., 1993)

They are classified into two types, old landslides and active landslide. The former was formed in recent geological age, from a few ten thousand years BP to a few decades years BP. Most of them are calm under usual weather or slope conditions at the present. However, they sometimes reactivate when the stability equilibriums on slopes are broken. Some of them reactivated as active landslides due to the earthquake. Slope failures are defined as shallow landslides that shallow or thin surface material slid down (Photo.3.5.2) and generally deposited on hill foot (Figure 3.5.1). These definitions are practical from the view point prevention measures. Deep landslides of which sliding masses remain on the slopes require stabilization of moving bodies, whereas countermeasures for slope failures are prevention of retrogression or extension of falling area on slopes.

Photo 3.5.1 Deep landslide（rotational landslide）northeast of Muzaffarabad city

Photo 3.5.2 Slope failures（shallow landslide）at Kulori

Quick Bird Images in scale of 1/5000 taken in November 2005 were used for detection of slope failures. Field studies that were carried in January, March, May and September 2006 also complemented data on slope failures. Quick Bird images were utilized as visual maps in filed sites to delineate small slope ruptures as signs of active landslides that were newly formed or reactivated by the earthquake. Topographic maps for the filed study were created using Digital Elevation Model (DEM) of 90 meters grid issued by NASA. This study also used IKONOS images of stereo pair in scale of 1/10000 taken in Sept. 2006 to detect old landslides. Three-dimensional interpretation of IKONOS images facilitated us to detect old landslides. Aerial photographs in scale of 1/30,000 and topographic map of 1/50,000 taken and prepared by Pakistan Government were also used for this study to know topographic conditions before the earthquake.

All ruptures, slope failures and landslides, detected in this study were digitized as polygon data on a digital map (1/25,000 and 1/10,000) created by IKONOS images. They were combined with DEM of five meters grid created from IKONOS images for GIS analysis. Slope surface ruptures were superimposed on topographic and geological maps to clarify the geotechnical conditions that are prone to cause landslides' phenomena in the Himalayan region. Slope gradient and average area of slope failures and landslides were also obtained by GIS method.

Study area is the Jhelum valley from Muzaffarabad at the west end to Chanli at the east end and it covers 255 km^2.

(2) Characteristics of distribution of landslides and slope failures

Slope failures of 4671 sites, newly formed active landslides of 76 sites and old landslides of 838 sites were recognized through this study (Figure 3.5.2).

Slope failures are usually marked by scars without vegetation on the slopes. Old landslides are marked by horseshoe shaped main scarps and ragged terrain of sliding mass in front of the scarp. Active landslides are noted by field studies.

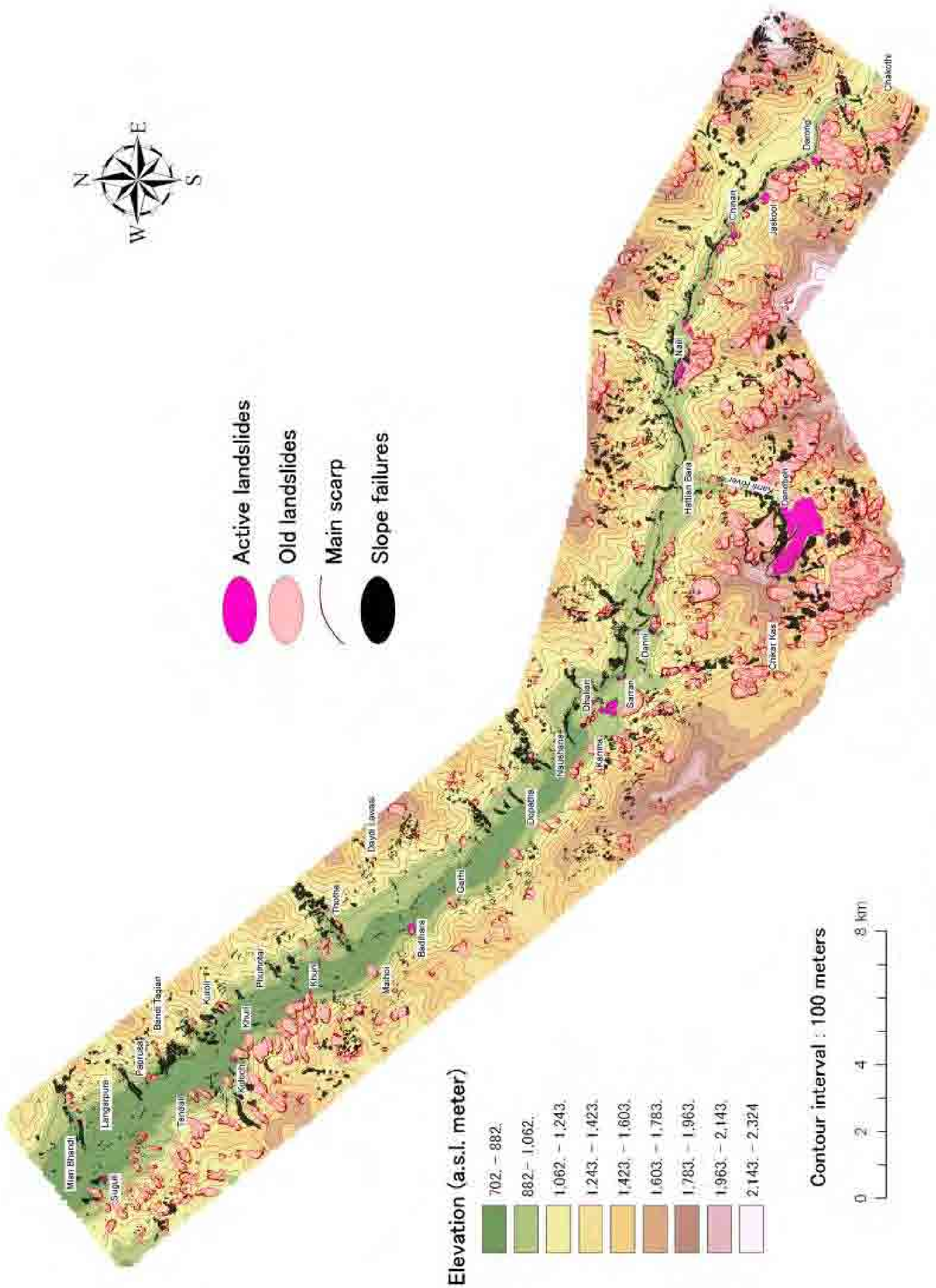


Figure 3.5.2 Distribution map of landslides and slope failures

As we mentioned above, all active landslides are reactivated ones of old landslides. We thought it is very important to clarify geomorphological and geological conditions where old landslides are located. Besides them, multi-genetic slope deformation such as tension cracks and up-hill facing scarps coupled with tectonic and subsequent gravitational movements were recognized along the active flexure scarp (Photo.3.5.3 and 4).

Photo.3.5.3 Tension cracks developed on the flexural scarp

Photo.3.5.4 Tension cracks developed on the flexural scarps at Dopatha

(3) Slope failures (Shallow landslide)

Slope failures caused by the 2005 Northern Pakistan Earthquake are strongly impressed by white big walls along the Balakot-Garhi Fault just behind Muzaffarabad city (Photo 3.5.5). They occurred on steep dolomite cliffs as marginal slopes fringing Muzaffarabad city to the north.

Photo.3.5.5 Slope failures on dolomite wall north of Muzaffarabad

In this study area, slope failures are marked as red colored bared slopes or scars (Photo 3.5.6). They are dominantly distributed along steep side slopes of tributaries that join to the Jhelum River and along terrace cliffs adjacent to the Jhelum River (Figure 3.5.2). They also occurred at toe parts and main scarps of old landslides. Large slope failures occurred on undercut slopes along the main stream of the Jhelum River. Photo 3.5.7 is a view of large slope failure on the undercut slope at Sugli. Slope failures do not much depend on geological condition (Figure 3.5.3) except unconsolidated terrace gravel, however, they frequently occurred on anti-dip slopes steeper than 35 degrees along the valley.

Photo.3.5.6 Red colored bared slope and scars

Photo.3.5.7 Large slope failure on under cut slope at Sugli

Scale of slope failure is relatively small compared with that of landslide. Average area of slope failure is 0.294 ha. Slope failure occurs on a relatively steep slope. Average slope inclination is 37.4 degrees and its mode is 37 degree (Fig.3.5.4). The number of slope failure increases, according to increase of slope gradient.

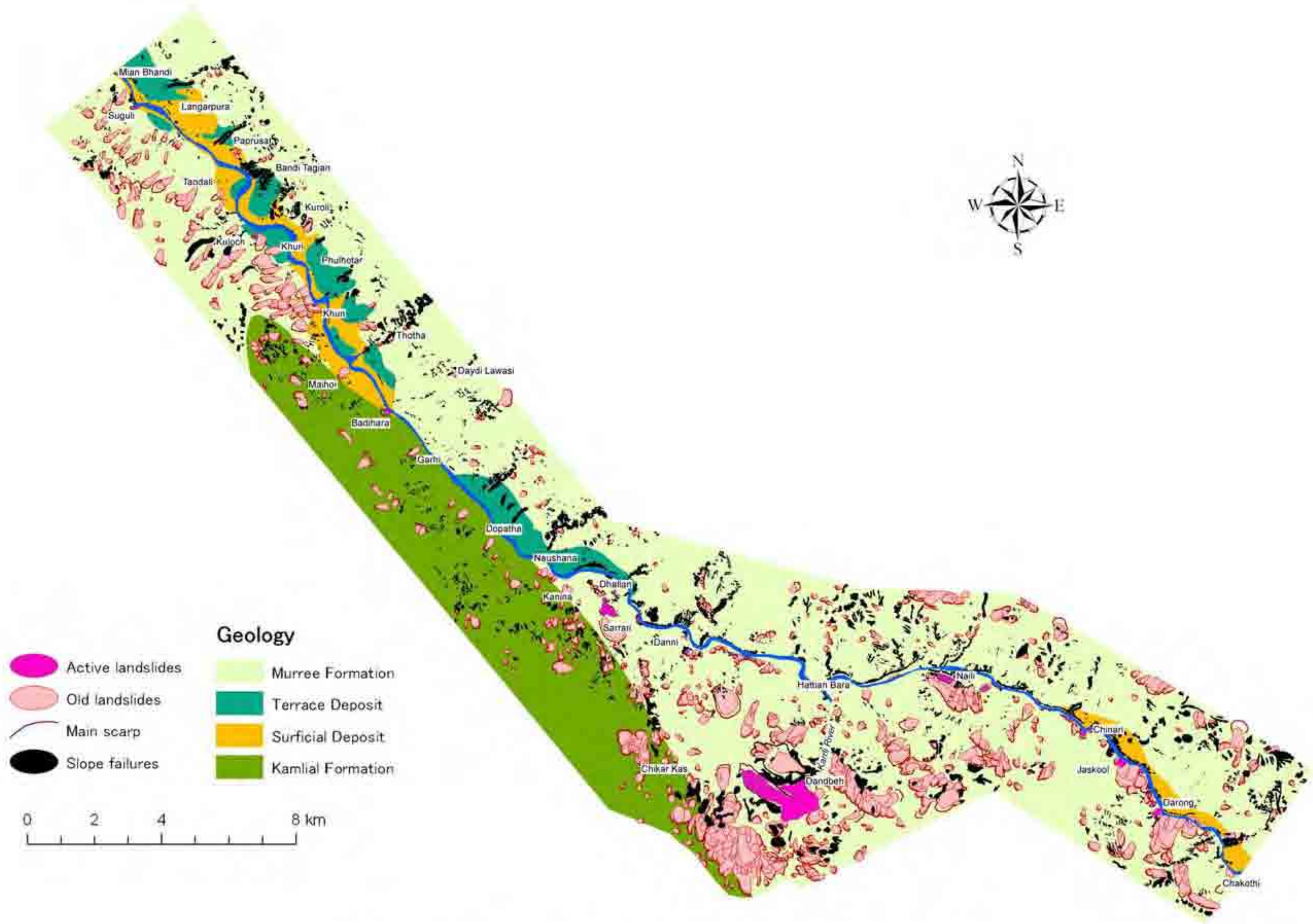


Figure 3.5.3 Landslide and slope failure distribution superimposed on a geological map

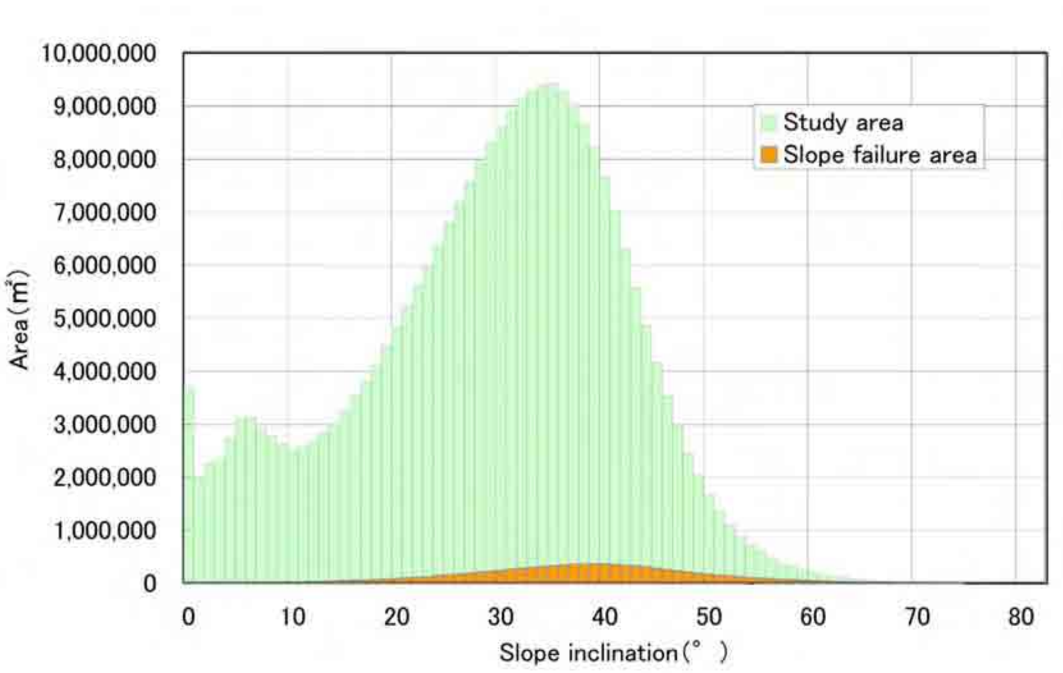


Figure 3.5.4 Occupancy rate of slope failures and slope inclination

(4) Old landslides (Deep landslides)

Landslides formed before the earthquake in this study area are spatially distributed unevenly (Figure 3.5.2). There are three areas where old landslides distribute densely. One is located on the left bank side of the Jhelum Valley in the lower course from Khun. The second is on the left bank area of the Jhelum River in the upper stream from Dhallan. The third is a watershed of the Karrli Mala River that joins to the Jhelum River at Hattian Bara. In other words, landslides are prone to occur in the zone of Muree Formation on the left bank of the Jhelum River (Figure 3.5.3). Occupancy ratio of landslides' area in a zone of Muree Formation to its whole area is 24% on the left bank of the Jhelum River. Muree Formation consists of alternates of silt and sandstones of Miocene to Pliocene.

Most of old landslides in Karrli Mala River watershed and left bank area of upper stream along the Jhelum River occur on dip slopes (Figure 3.5.5). This implies that occurrence of landslides in the Muree Formation zone heavily depends on the slope type whether it is dip slope or anti-dip slope that is determined by the combination of slope direction and geological structure. Old landslides are also distributed in the area of anti-dip slope south of Kuloch in the lower course (Photo 3.5.8). They slid obliquely to the bedding plain as wedges. We should deliberate the cause of landslides on anti-dip slope in the Muree Formation area in the lower course of the valley. Initial stage of a rock slide is just occurring on an under cut slope at Badihara where is underlain by the Muree Formation and is developing as the anti-dip slope (Photo 3.5.9). This implies that the Muree Formation is prone to landslide on anti-dip slopes under the condition of sever under cutting at the present. And it also suggests that old landslides had initially occurred under same erosional conditions in the incision process along the Jhelum Valley in the past.

Photo 3.5.8 Old landslides near Kuloch

Photo 3.5.9 landslide on anti-dip slope at Badihara

Old landslides are also distributed in a zone of the Kamlial Formation along a contact zone with the Muree Formation, though occurrence ratio in this zone is relatively low as a whole. The Kamlial Formation is alternates of coarse sand stones and conglomerates, suggesting original strength is harder than that of the Muree Formation. This implies that faulting affects rock strength in relation to the occurrence of landslides.

Average area of old landslides is 3.3 ha, however, relatively large landslides occur in the upper course area from Naushana. This difference is attributed to difference of cross section type of the Jhelum Valley. In the upper stream from Dhallan it shows the gorge type deeper than 100 meters, steep and deep side slope along the gorge have moved gradually.

Average inclination of landslide mass is 30.9 degrees and its mode is 29 degrees. Namely deep landslides occur on relatively gentle slope compared with slope failure (Figure 3.5.6).

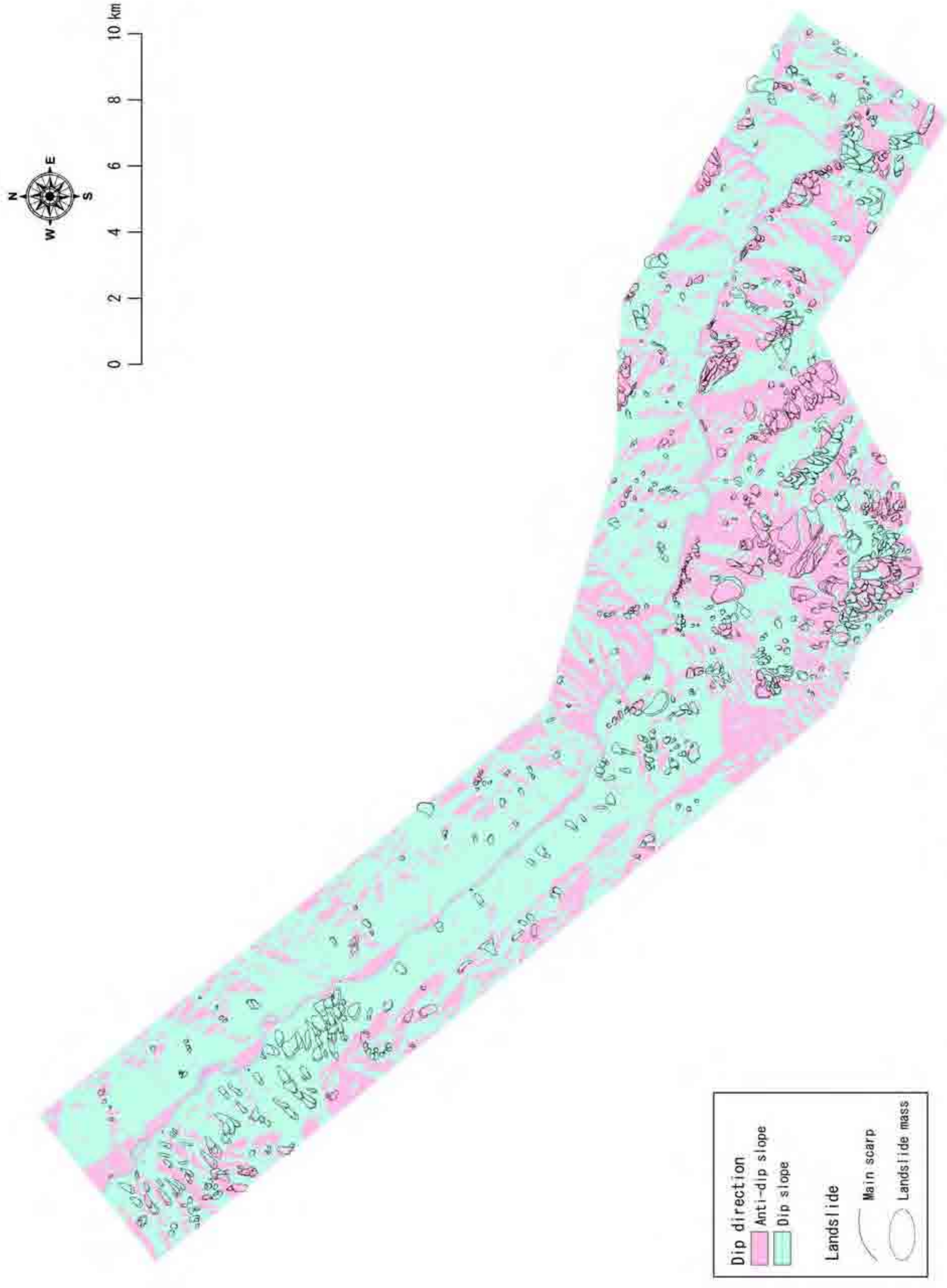


Figure 3.5.5 Distribution of old landslides on a slope-structure map

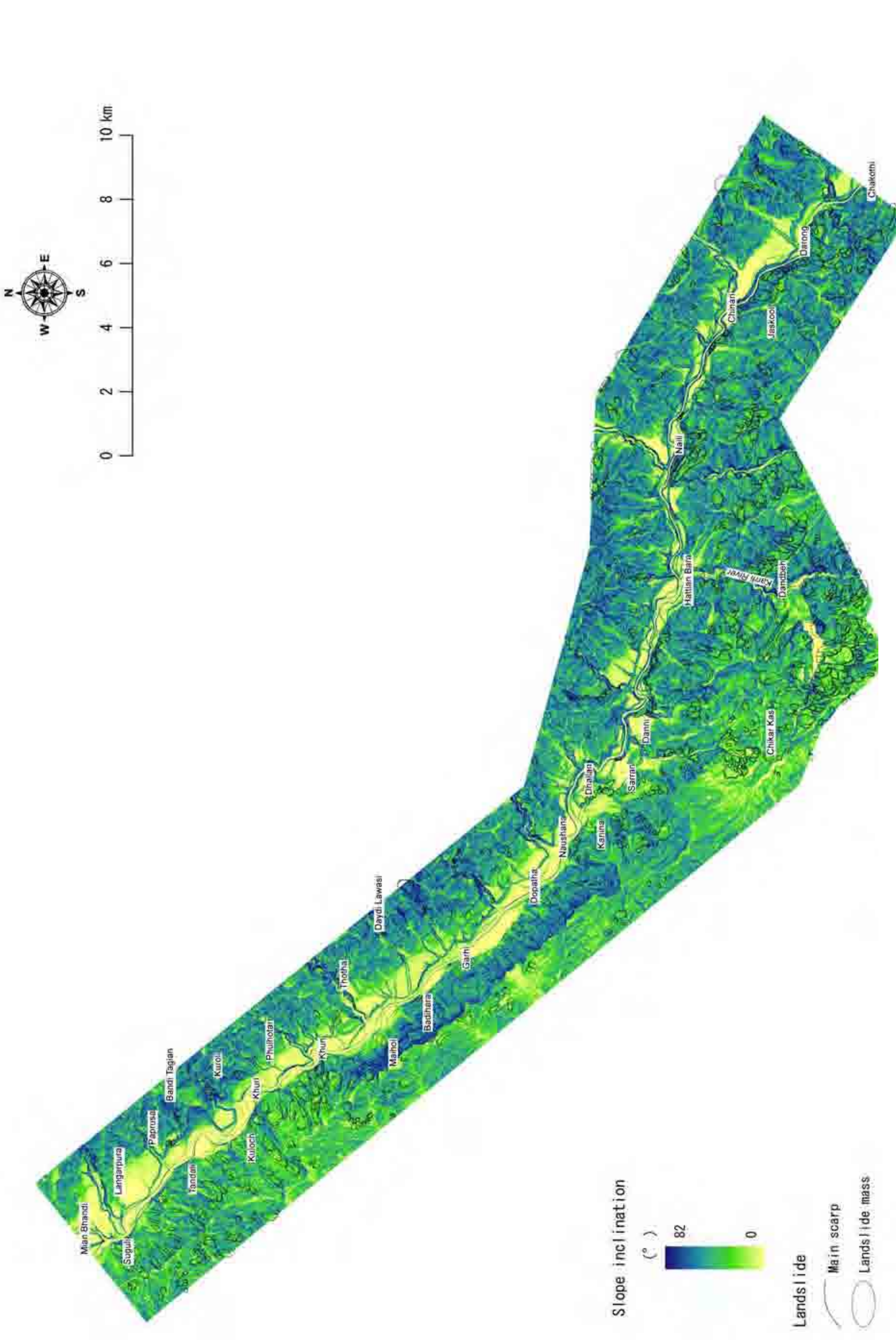


Figure 3.5.6 Distribution of old landslide on a slope indication map

(5) Active landslides

Deep landslides causing recent displacement on slopes or artificial structures were checked by filed studies after the earthquake. We call them active landslides. They are usually reactivation of old landslides. In most cases, toe parts of the old landslides that developed as undercut slopes just adjacent to the Jhelum River became active (Photo 3.5.10), accelerated by the 2005 Northern Pakistan Earthquake. The topographic profile of the active landslide is characterized by steep cliff more than 50 degrees, suffering strong river erosion at the base. In some cases, civil engineering works as road construction carried out along the foot of undercut slopes affected slope stability (Photo 3.5.11). Displacements of road surface ranging from a few centimeters to two meters were observed (Photo 3.5.12 and 13), suggesting the slide surface reaches to river floor. Scale of land-sliding area in the lower course area is smaller than that in the upper course area due to its cross section type as mentioned above.

Photo 3.5.10 Reactivated landslide due to toe erosion

A large active landslide at Naili is located along the gorge in the upper course of the Jhelum River. It is also a reactivated old landslide, its toe part as an undercutting slope that consists of weathered rock or earth is bulging towards the Jhelum River. Area of the old landslide covers a whole slope from the river bed to the top of ridge (Photo. 3.5.14 and Figure 3.5.7)

The most distinct example of the reactivated landslide is the Dandbeh landslide (Photo 3.5.15). Geomorphological map made by interpretation of aerial photographs taken in 1978 clearly shows pre-existed slope dislocation marked by cracks and small cliff on the original slope and ridge (Figure 3.5.8).

Photo.3.5.11 Active landslide due to under cutting and civil works at Jaskool

Photo.3.5.12 Slight displacement of road pavement as a sign of a deep active landslide

Photo.3.5.13 Dislocation of retaining wall due to active land-sliding of weathered rock or earth

Photo.3.5.14 panoramic view of Nail landslide active part(front) & old part(behind)

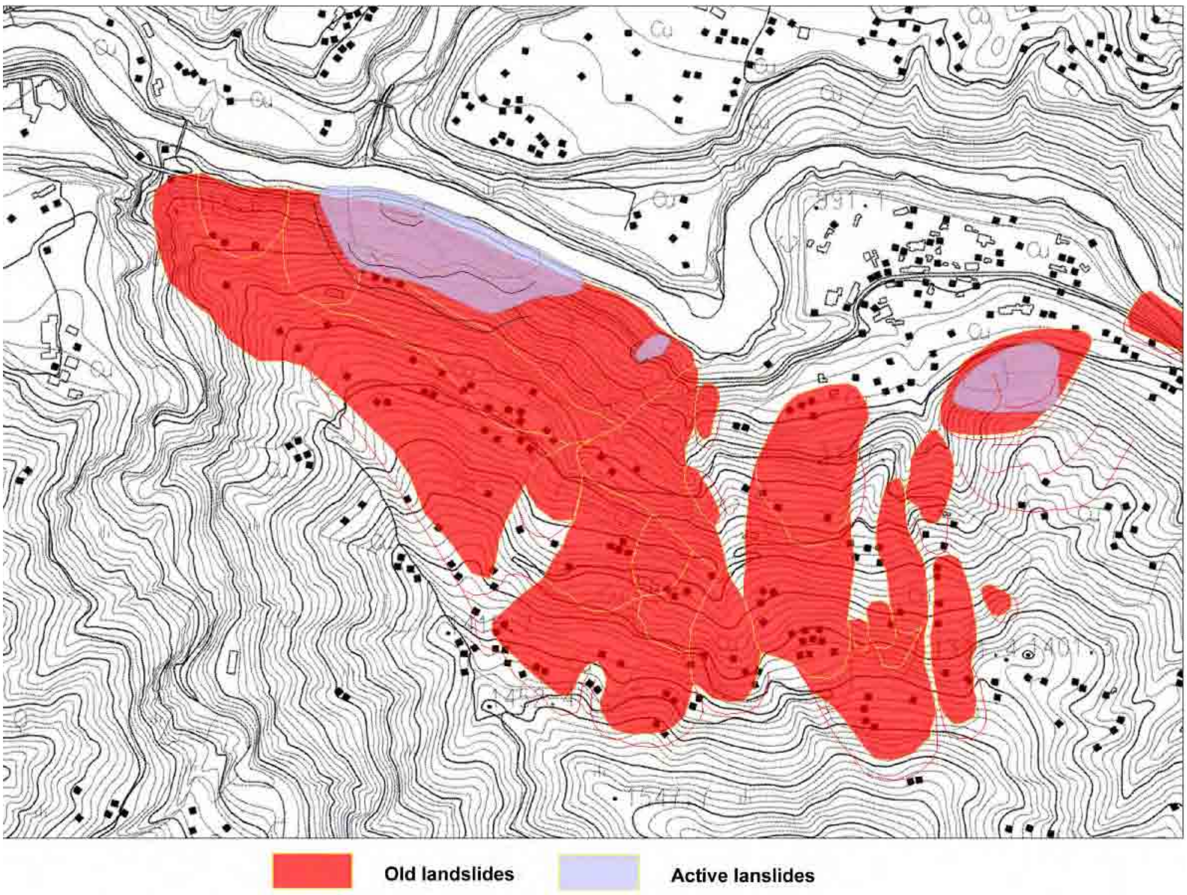


Figure 3.5.7 Plane map of Naili landslide

Photo 3.5.15 Dandbeh landslide as a reactivated landslide

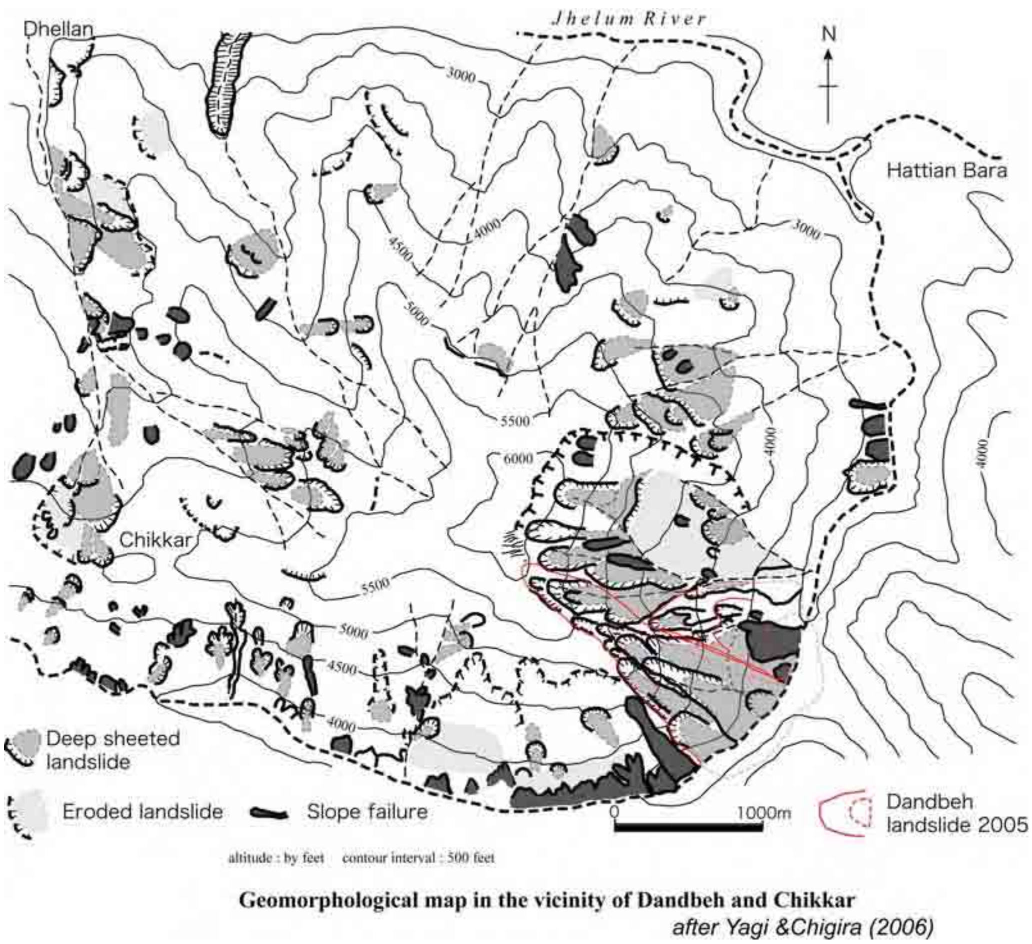


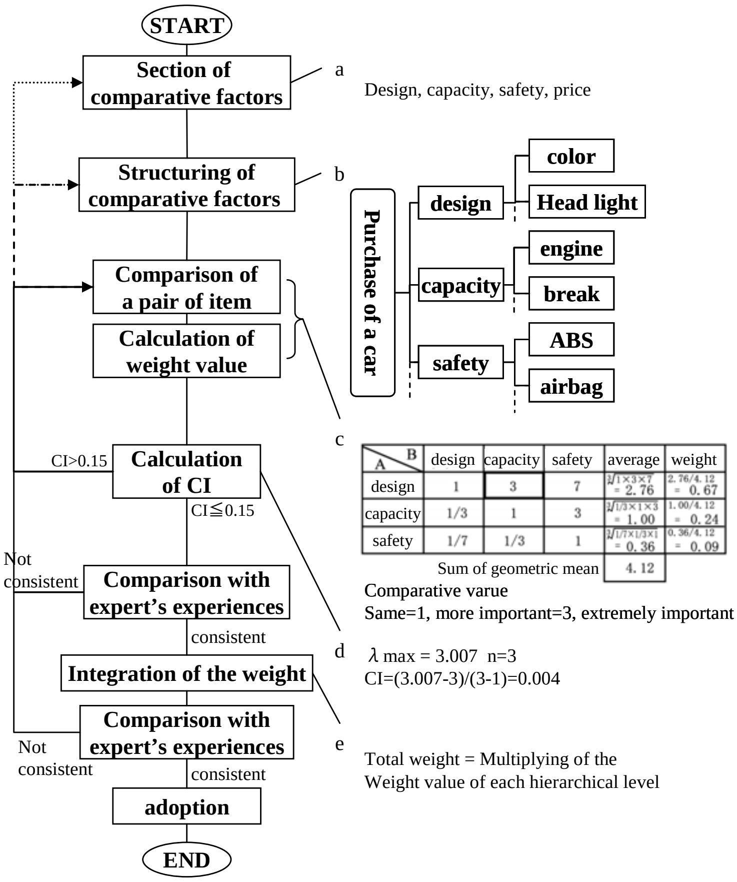
Figure 3.5.8 Geomorphological map in the vicinity of Dandbeh and Chikkar (after Yagi & Chigira, 2006)

3.6 Hazard assessment of landslides along the Jhelum River

(1) Adoption of AHP landslide hazard assessment system

After the detection of the slopes formed by landslides (deep landslide), preliminary hazard assessment can be executed by the aerial photo interpretation of the microtopography and topographical setting of each landslide slope. An expert system by using AHP method (Analytic Hierarchy Process developed by Satty T. L.(1971)) for landslide hazard assessment has been developed by the Japan Landslide Society and the Ministry of Construction, Japan (2002) based on the interview and brain storming of the experts in aerial photo interpretation and reconnaissance survey of landslide.

The AHP method decomposes the process of subjective judgement of people into a layer structure and express the process qualitatively. The flow chart of AHP modeling is shown as the case of purchasing a car in Figure 3.6.1. This model has been developed for numerical processing of decision making based on the experiences.



A \ B	design	capacity	safety	average	weight
design	1	3	7	∛1×3×7 = 2.76	2.76/4.12 = 0.67
capacity	1/3	1	3	∛1/3×1×3 = 1.00	1.00/4.12 = 0.24
safety	1/7	1/3	1	∛1/7×1/3×1 = 0.36	0.36/4.12 = 0.09
			Sum of geometric mean	4.12	

Figure 3.6.1 Flow chart of AHP modeling

Five geomorphic and kinetic factors have been selected as the hierarchical level Ⅱ(Table 3.6.1) based on the brain storming among experts who have geomorphologically experienced field inspection of landslides both in Pakistan and Japan.

They are:

1) Clearness of main scarp,

2) Surface feature of landslide body,

3) Position of landslide block on the slope,

4) Position of slope failure in the landslide body,

5) Stability condition of landslide toe.

Factor 5) consists of 5)-1 Erodibility of the landslide toe and 5)-2 Feature of the landslide toe.

Table 3.6.1 Weight value for AHP landslide hazard assessment

Level II	Weight	Level III	Weight	Weight coefficient	Score
Clearness of main scarp	0.08201	Clear	0.6029	0.0494	4.94
		Slightly clear	0.2915	0.0239	2.39
		Unclear	0.1055	0.0087	0.87
Surfacial feature of landslide body (Clearness of landslide microtopography)	0.12005	Clear	0.5894	0.0708	7.08
		Slightly clear	0.2873	0.0345	3.45
		Unclear	0.1233	0.0148	1.48
Position of landslide block	0.08581	Toe	0.605713	0.0520	5.20
		Middle	0.129951	0.0112	1.12
		Head	0.070013	0.0060	0.60
		Indivisual	0.1943	0.0167	1.67
Position of slope failure in the landslide body	0.16858	Head	0.1155	0.0195	1.95
		Middle	0.1467	0.0247	2.47
		Toe	0.7379	0.1244	12.44
		None	0.0000	0.0000	0.00
Stablity condition of landslide toe (Erodibility of the landslide toe)	0.30407	High	0.6009	0.1827	18.27
		Medium	0.3076	0.0935	9.35
		Low	0.0914	0.0278	2.78
(feature of the landslide toe)	0.23948	Unstable	0.6217	0.1489	14.89
		Slightly stable	0.2844	0.0681	6.81
		Stable	0.0940	0.0225	2.25
				1	100.00

These all factors correspond to three principal factors which are geomorphic evolution processes, landslide activity and destabilizing possibility. The factors 1) and 2) indicate the recent activity of landslide from the viewpoints of geomorphic evolution processes , since ancient landslides can easily be dissected or denudated by various erosion processes other than landslide itself. Microtopographical features such as scarps, cracks and mounds gradually become unclear.

The factor 3) means the position of a landslide block susceptible to destabilization of a landslide based on the landslide block evolution. Blocks located on the lower part of the multi-block landslide slopes are generally rather susceptible in case of progressive block evolution because they tend to be composed of clayey soil with groundwater.

The factor 4) indicates recent activity of the landslide often indicated by slope failures (shallow landslide) which generally occur at the lower part of moving body.

The factors 5)-1 and 5)-2 relate to be the possibility of destabilization of a landslide by toe erosion and consequent decrease in slope stability. Erodibility of the landslide toe is landslide toe is large in case that the toe is facing undercut slope of the river rather than non-under-cutting slope. The erodibility also depends on the stream order such as main stream, tributary and smaller torrent.

The hierarchical level Ⅲ indicates the classified emerging cases of each geomorphic and movement factor.The weight values of these factors under the same hierarchical level are obtained from the weight assessment of each comparative factor by the same experts as that of comparative factor selection (Table 3.6.1). Final weight coefficient for hazard rating is calculated by multiplying the value of hierarchical class Ⅱ and Ⅲ.

This system is prepared for the preliminary landslide hazard assessment mainly by aerial photo interpretation. Field surveys and verification are essential to assess the probability of occurrences of the highly rated landslide slopes.

Classification of hazard level can also be decided considering frequency distribution of the score of each landslide slopes by both statistical analysis of real landslide inventory and administrative decision. Fig.3.6.2a shows the frequency distribution of scores for the landslides along the Muzaffarabad-Kashimir highway by the AHP landslide hazard assessment system. We focused on deep landslides with the possibility of reactivation for the hazard rating.

The cumulative curve of frequency distribution shows some knick points in its inclination. Based on it, we classified the scores for each landslide into five degrees of hazard from high scores to lower which are very high, high, moderate, slight and very slight respectively(Fig. 3.6.2a). The rank of scores for each hazard level is: very high:S>90, high:90>=S>70 , medium:70>=S>60, slight:60>=S>20 and very slight:20>=S.

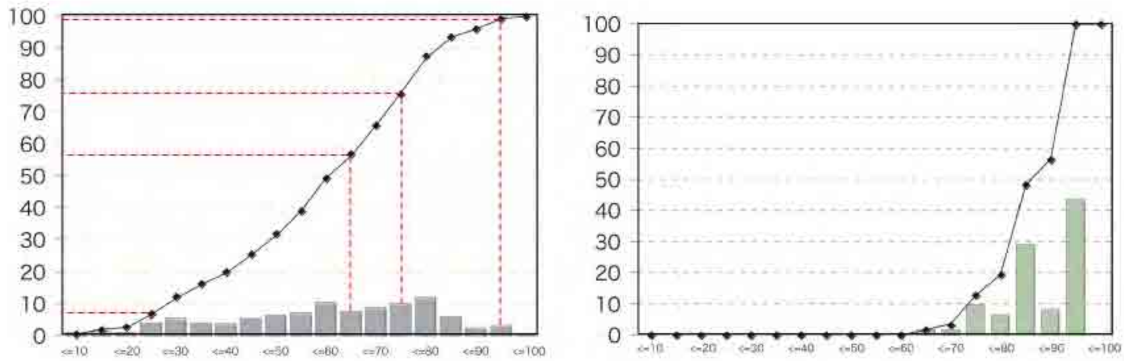


Figure 3.6.2 Frequency distribution of the scores for (a) whole landslides detected (left) and (b) the active landslides (right)

Active landslides where recent landslide phenomena such as cracks, steps and other symptom of displacement have been observed after the earthquake are mostly evaluated to be urgent or dangerous (Figure 3.6.2(b)). This indicates that the adopted method can evaluate landslide hazard properly.

(2) Distribution of landslide hazardous slopes

As above mentioned, this study has already clarified that key words related to dislocation of slopes due to the 2005 Pakistan earthquake are reactivation of the old landslides. Consequently, paying much attention to the old landslides that have high potentiality of reactivation in future is a priority matter, especially for the personnel of Pakistan Government in charge of rehabilitation and reconstruction programs in this area. From this point of view, degrees of landside hazard were assessed for all old landslides distributed in the study area of the Jhelum Valley. All old landslides were checked every weighting items of AHP analysis by interpretation of stereo paired IKONOS images in scale of 1/10,000. Fig.3.6.3 shows the degree of landslide hazard for each old landslide by different colors. Warm colored areas indicate relatively higher potentiality of reactivation. It shows that there are three areas of high potentiality of reactivation of land-sliding;

The first is a group of the old landslides distributed adjacent to the landslide dam lake at Dandbeh.

The second is a group of toe parts of the large old landslides located on the left bank in the upper stream of the Jhelum River east of Dhallan.

The Third is a landslide cluster distributed between Khun to Khuri on the left bank of the Jhelum River in the lower course of the valley.

The first and second groups are considered as urgent. Reactivation of the first group due to rise of ground water level related to formation of the natural dam is worried. Surge triggered by plunge of landslide mass into the natural lake will cause secondary disasters such as out break of the landslide dam and subsequent mud flow in the lower course. It will be a catastrophe. The most problematic slopes are the second groups' that are located on the steep and long under cut slopes undergoing sever toe erosion by the torrential stream of the Jhelum River. Furthermore, they are distributed in Muree Formation zone on dip slopes. Long term gravitational rock creep, subsequent topples and slide have been widely taking place on the whole upper slopes adjacent to the gorge. Huge driving force derived from the whole slopes leans against the fractured and weathered rock in the toe part. It will be quite difficult to cope with such fragile slopes by a partial countermeasure. Political decision on alignment change of the road will be desirable from the view point of hazard assessment. The right bank of the Jhelum River is assessed relatively low in degree of landslide hazard.

Reference:

Aganogawa River Work office & Japan Landslide Society (2002), Report of Landslide risk map (in Japanese), 1-71

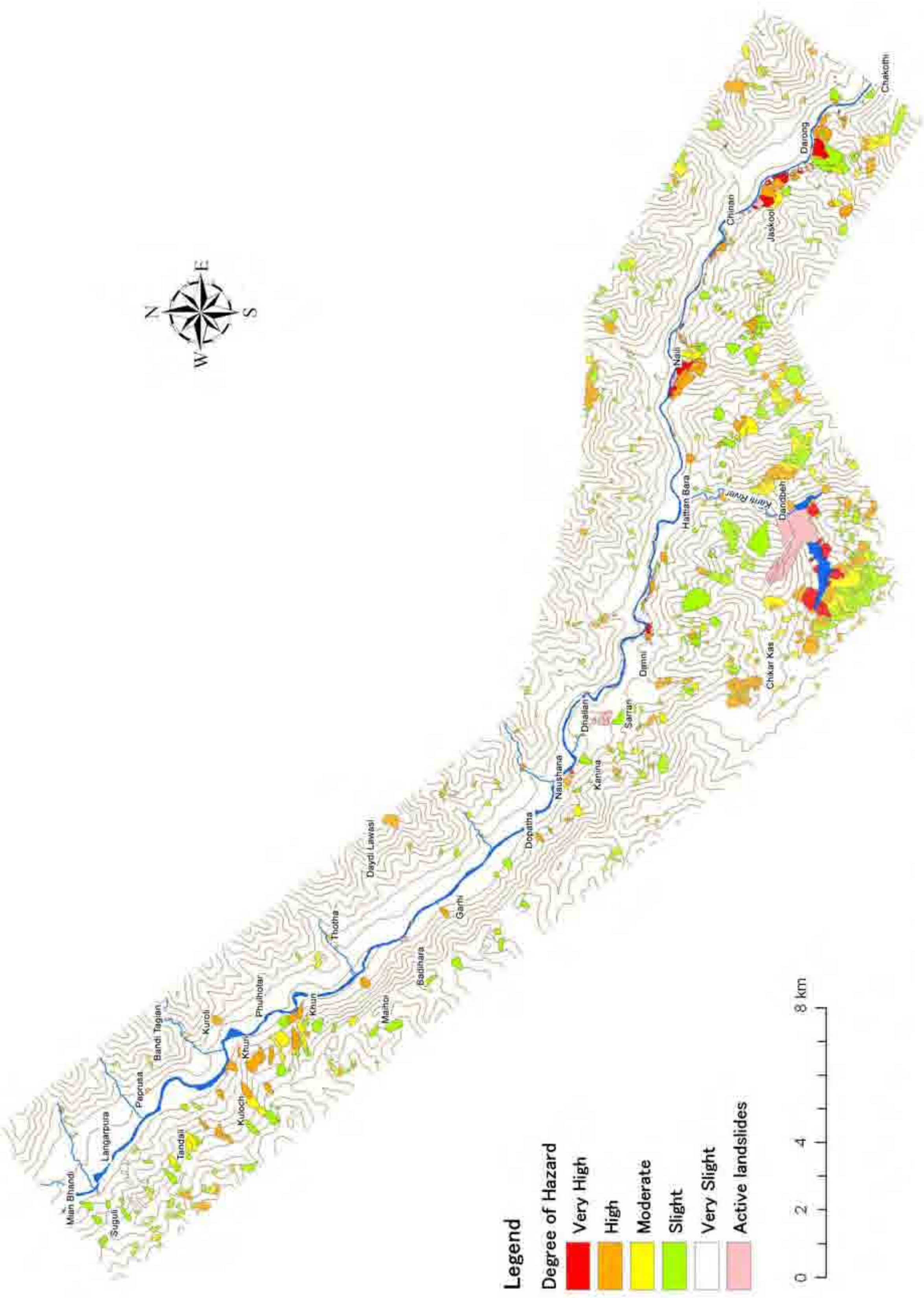


Figure 3.6 3 Landslide hazard assessment by AHP (Analytical Hierarxhy Process)

3.7 Hazard assessment on slope failures along the Jhelum River

(1) Objective and method

The objective of the hazard assessment is to predict occurrence of slope failures along the Jhelum River in the future. The final goal is to make up a hazard assessment on map on slope failures. For topographical analysis, IKONOS satellite image was used and a set of topographical data with resolution of 5m mesh was arranged. For geological examination, geological maps in scale of 1:50000 made by the Geological Survey Pakistan were used. Slope failures were extracted by interpretation of IKONOS and Quick bird satellite images. On the basis of the results of past field inspections, the following topographical and geological factors in Table.3.7.1 (Determining factors and allocated points for hazard assessment) were selected in order to assign degrees of hazard from slope failures. The relationship between these selected factors and distribution of slope failures was examined for hazard assessment. Allocation of points on degrees of hazard from slope failures was carried out based on the statistical treatment. The degrees of hazard from slope failure were assessed by the total points on all selected factors. Detailed allocation procedure of points will be described later. Analysis for hazard assessment and output of risk evaluation map were carried out using 5m mesh unit.

Table 3.7.1 Determining factors and allocated points for hazard assessment

Determining facotrs			Allocated points		
			0	0.5	1
Topographical factores	Slope inclination		$\theta < 36°$	$36° < \theta < 64°$	$64° < \theta$
	Undercut slope	Along main river	Other areas	Intersection angle lower than 35°	Intersection angle larger than 35°
		Along tributaries	Other areas	Intersection angle lower than 60°	Intersection angle larger than 60°
Geological factores	Geology		No clear relationship		
	Dip direction		No clear relationship		
	Distence from earthquake fault		No clear relationship		

(2) Results

Distribution of slope failures and classification of slope inclination are shown in Figure 3.7.1 (Slope failure distribution and slope inclination). The ratio of slope failure area to the total area in each slope inclination class increases with the increase of slope inclination. The ratio amounts to only several percents among slopes with inclination of 0 – 36 degrees. However, the ratio amounts to 30 – 50 percent among slopes steeper than 60 degrees. In consideration of these results, the allocated point for the slopes steeper than 64 degrees was determined to be 1 point. The allocated point for the slopes with inclination of 36 – 64 degrees was determined to be 0.5 point. The allocated point for the slopes gentler than 36 degrees was determined to be 0 point.

Distribution of slope failures and distribution of undercut slopes are shown in Figure 3.7.2 (Slope failure distribution and undercut slope). It is clearly observed that the probability of slope failure occurrence is significantly high at undercut sections. It is also clearly observed that the probability of slope failure occurrence is significantly high at critical undercut sections with intersection angle larger than 35 degrees along the main river and at critical undercut sections with intersection angle larger than 60 degrees along the tributaries. Therefore, for the main river, the allocated point for undercut sections with intersection angle larger than 35 degrees was determined to be 1 point and the allocated point for undercut sections with intersection angle smaller than 35 degrees was determined to be 0.5. For the tributaries, the allocated point for undercut section with the intersection angle larger than 60 degrees was determined to be 1 point and the allocated point for undercut sections with intersection angle smaller than 60 degrees was determined to be 0.5.

The relationship between distribution of slope failures and geology, dip direction and distance from the earthquake fault are shown in Figure 3.7.3 (Slope failure distribution superimposed on the geological map), Figure 3.7.4 (Slope failure distribution and dip direction), Figure 3.7.5 (Slope failure distribution and distance from the earthquake fault) respectively. As no clear relationship can be seen in these figures, such geological factors were not used for the hazard assessment.

As a result, the degrees of hazard from slope failures were assessed on each individual 5m mesh unit by the total allocated points on topographical factors only. The hazard assessment map is shown in Figure 3.7.6 (Slope failure hazard assessment map). The slopes which have similar topographical characteristics with the failed slopes by the Northern Pakistan Earthquake, such as steep slopes in mountainous areas, terrace scarps along river courses and slopes at undercut sections, were assessed to have high degrees of hazard from slope failures in the future.

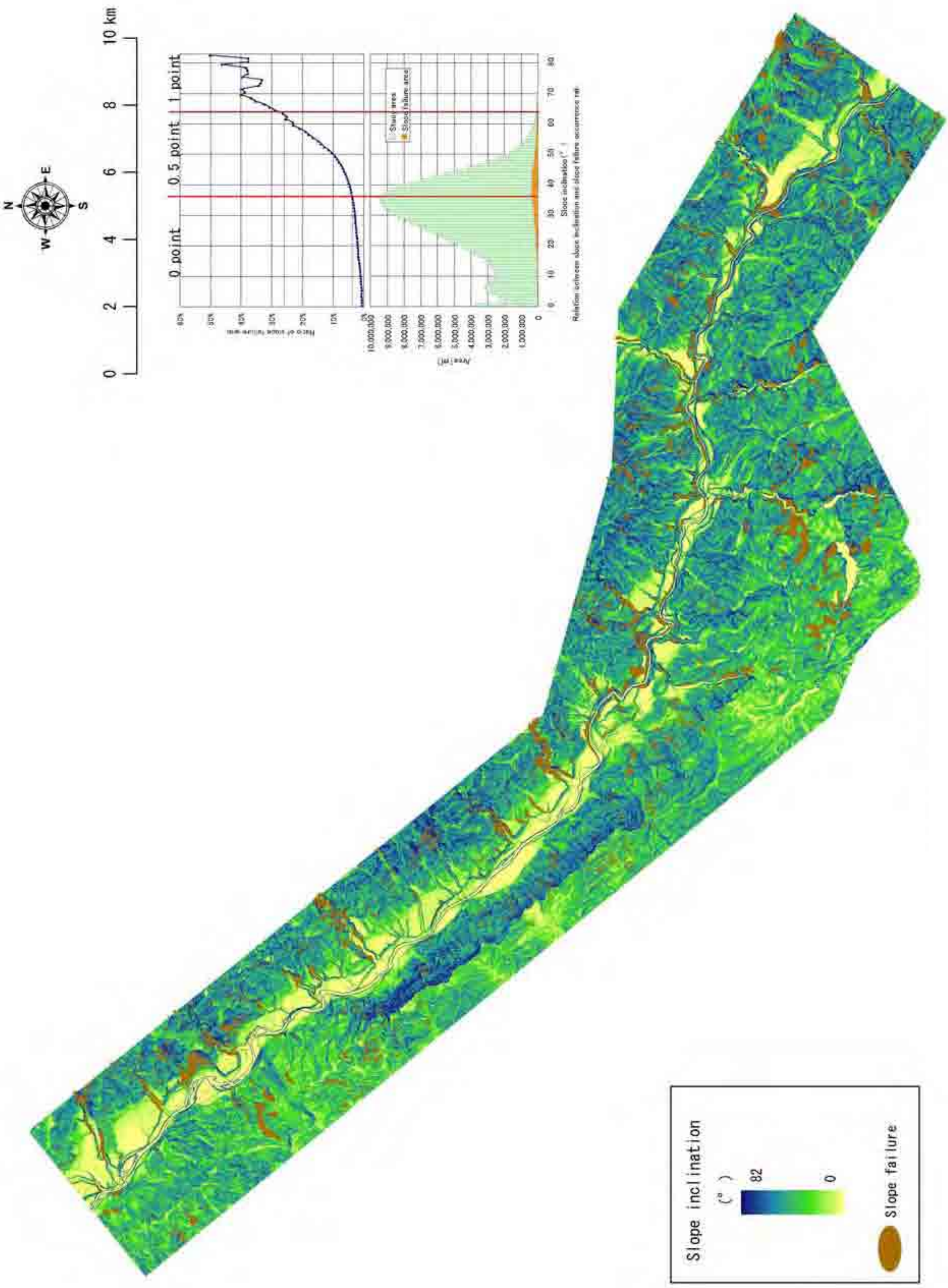


Figure 3.7.1 Slope failure distribution and slope inclination

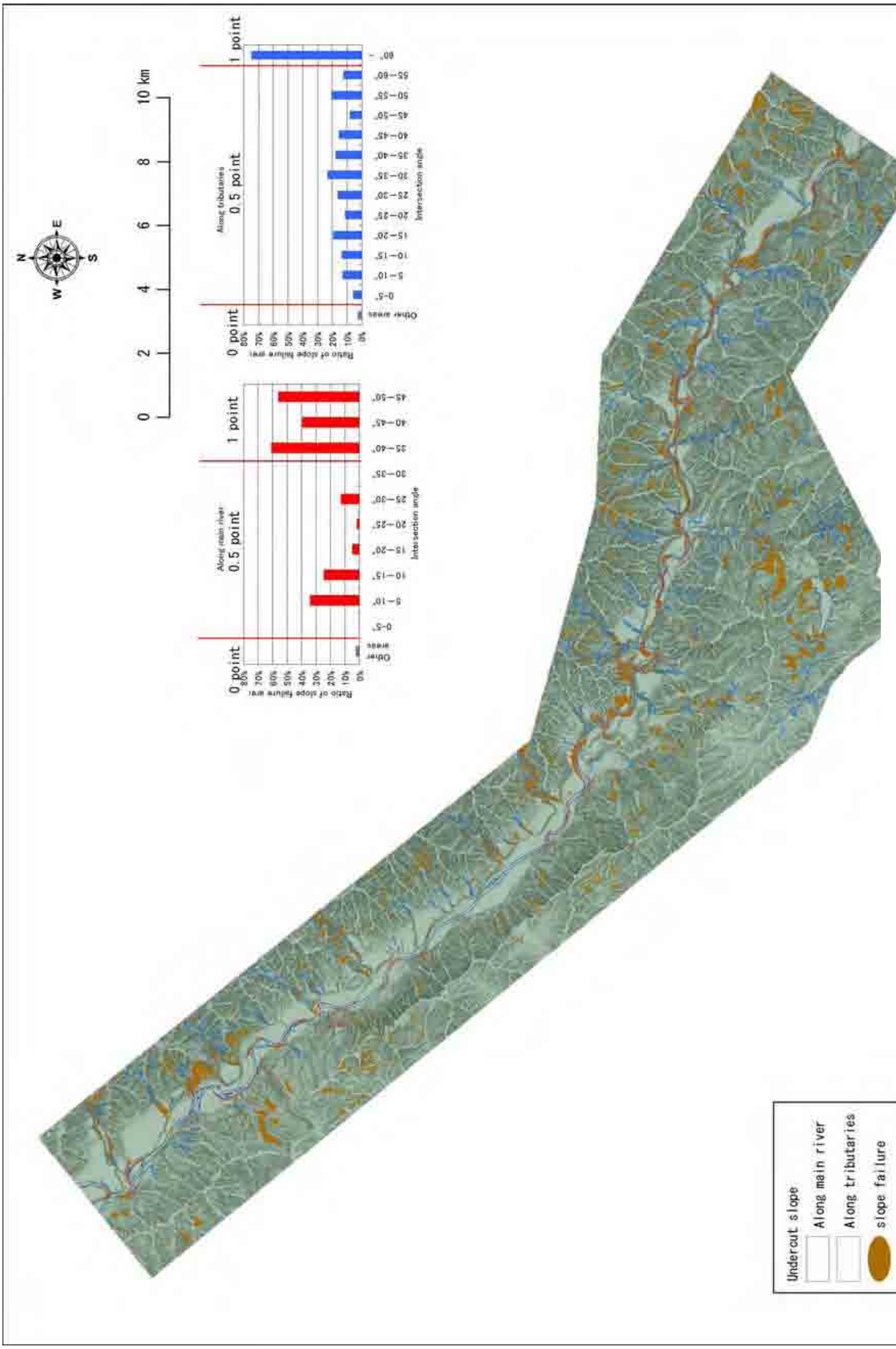


Figure 3.7.2 Slope failure distribution and undercut slope

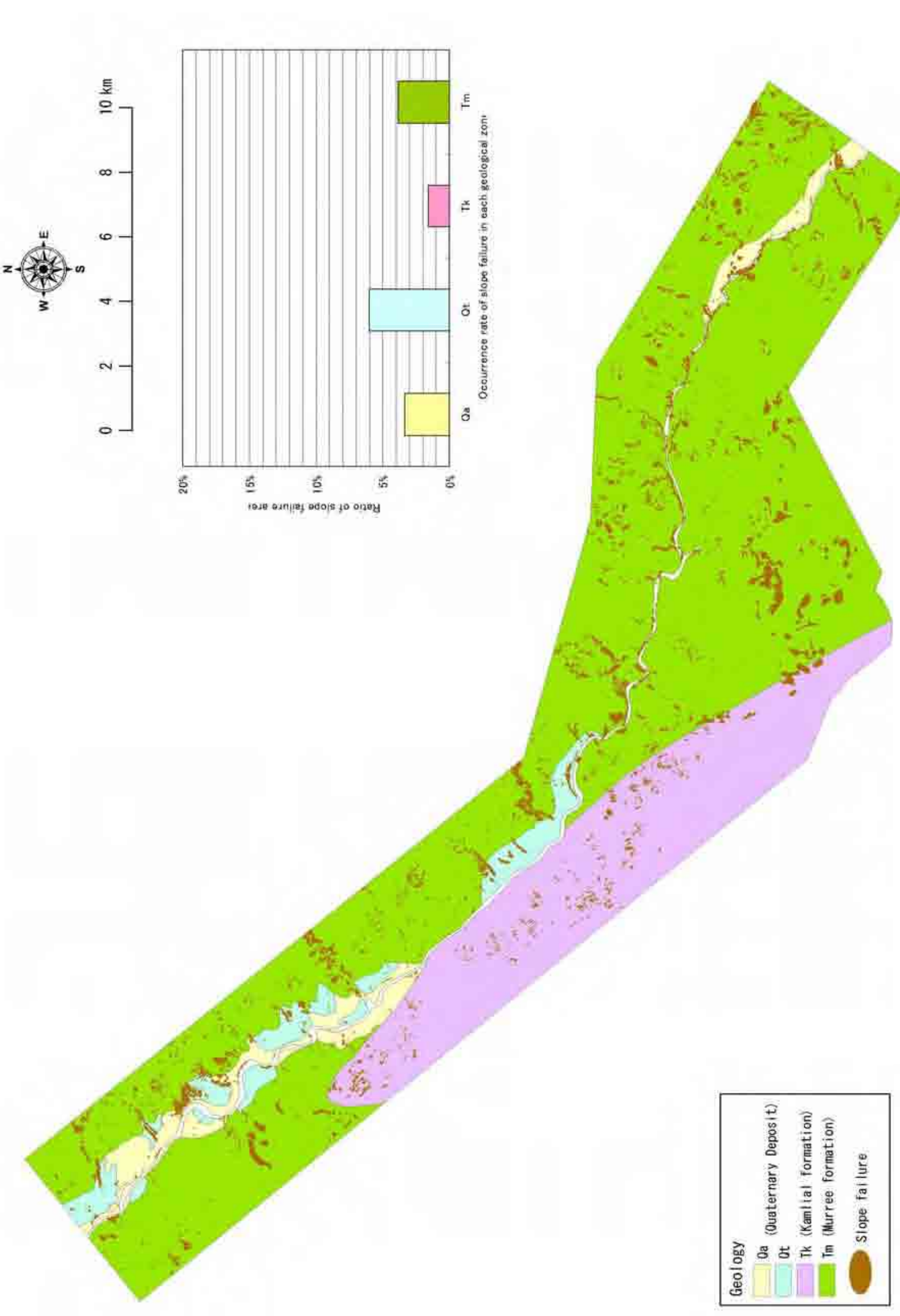


Figure 3.7.3 Slope failure distribution superimposed on geological map

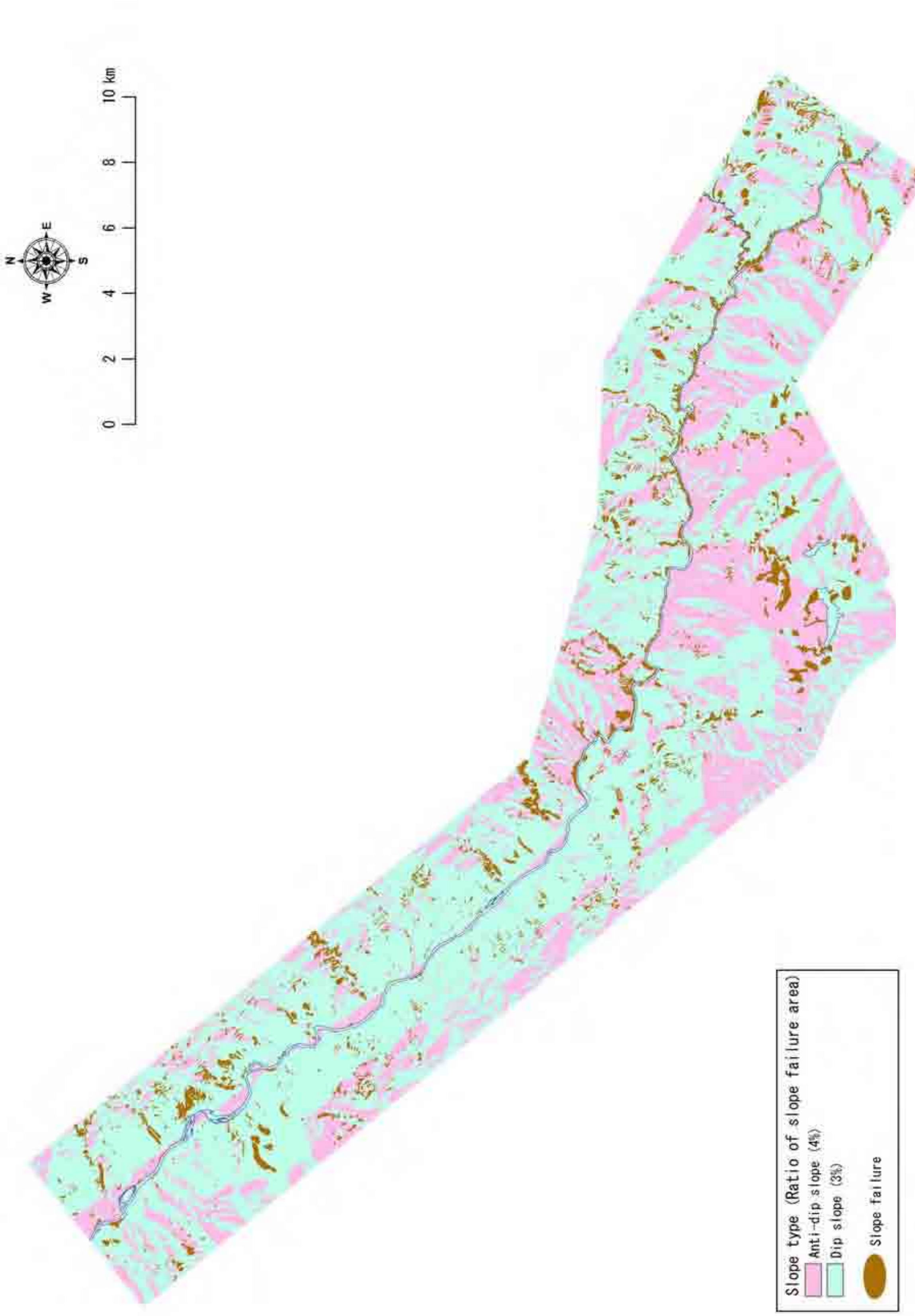


Figure 3.7.4 Slope failure distribution and dip direction

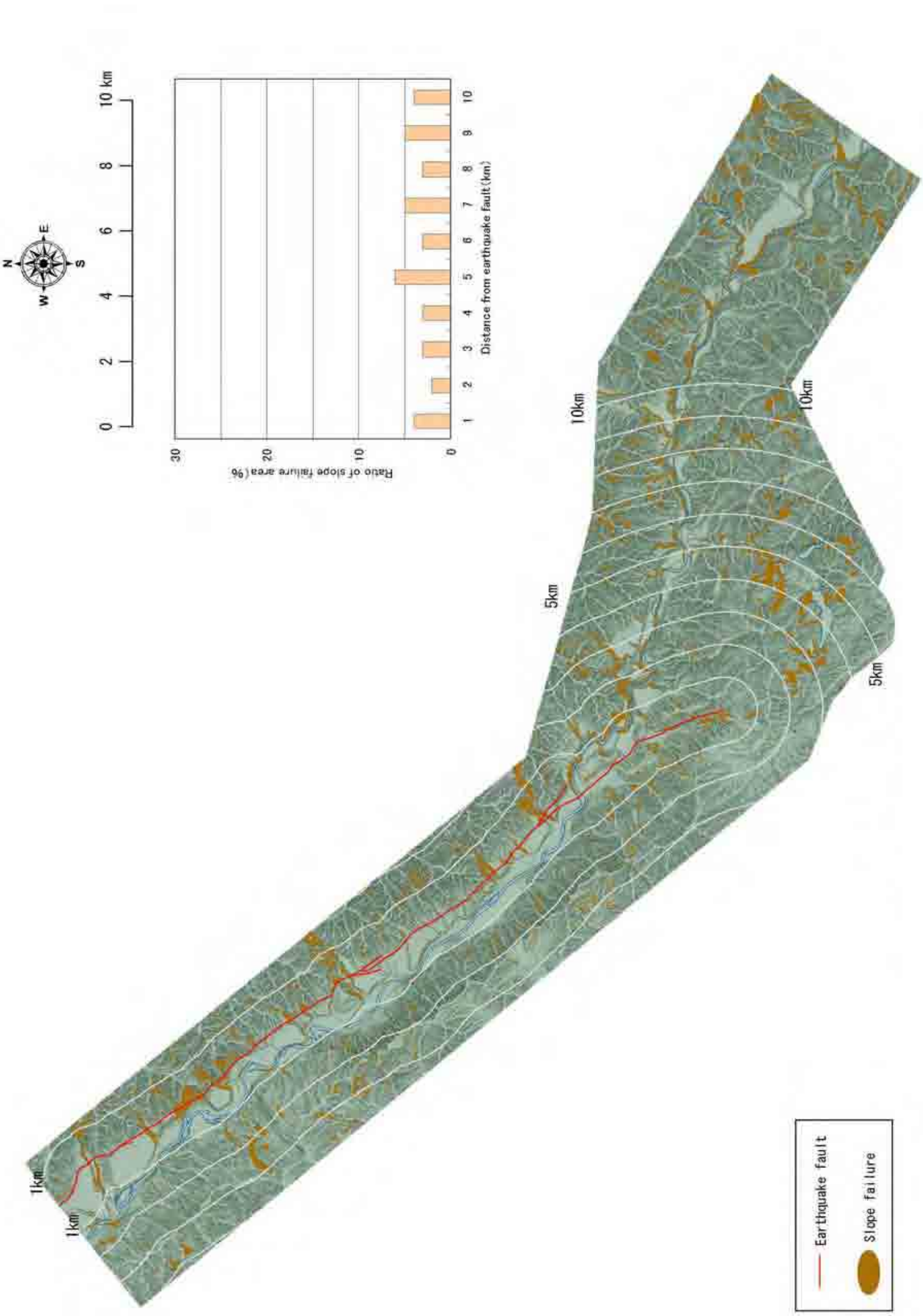


Figure 3.7 5 Slope failure distribution and distance from earthquake fault

Figure 3.7.6 Slope failure hazard assessment map

3.8 Assessment of debris flow hazard after the Northern Pakistan Earthquake

Various types of mass movements such as landslides and slope failures caused by the 2005 Northern Pakistan Earthquake have increased the possibility of debris flow occurrence in the tributaries of the Jhelum River. Preliminary assessment of debris flow hazard in the watersheds of those target tributaries has been conducted by interpreting topographical setting of each individual tributary, distribution of unstable debris materials produced by the earthquake induced mass movements and location of settlements as potential suffering areas from possible debris flows using IKONOS images. The results of this assessment should be examined by field investigations. It is also necessary to develop a more sophisticated method for assessment of debris flow hazard.

By interpretation of IKONOS images of the right and left bank tributaries of the Jhelum River along the section from Dhanni to Dallan as shown in Figure 3.8.1, the following factors for assessment of debris flow hazard have been evaluated and graded as shown in Table 3.8.1.

The necessary factors are:

- Existence of old and active landslides and slope failures in the watershed of each tributary,
- Gradient of the riverbed of each tributary at the confluence to the Jhelum River,
- Relative volume of unstable debis materials on the riverbed of each tributary,
- Length of each tributary,
- Existence of houses around the confluence to the Jhelum River and within around 2km downstream from it,
- Existence of cultivated land in the same areas as factor 5),
- Existence of bridges within around 2km downstream of the confluence to the Jhelum River,
- Possibility of channel blockage along of the Jhelum River by a debris flow.

Results of the assessment of debris flow hazards on the basis of the evaluation of each individual factor mentioned above are described by grading into three categories, namely high, medium and low, as follows:

1) Distribution of landslides (both old ones before the earthquake and new ones caused by the earthquake) has been grasped. Slope failures caused by the earthquake have

been classified into three categories, namely terrace-cliff type, mountain slope type and upper watershed type according to their location. The total area of the whole slope failures in a watershed has been classified into three categories, namely large (L), medium (M) and small (S). These landslides and slope failures can be the source areas for debris flow materials.

2) Generally debris flow can flow downward on the slopes steeper than 3 degrees in gradient. Such case is shown by a circle in Table 3.8.1.

3) Relative volume of unstable debris materials on the riverbed of each tributary has been classified into three categories, namely large (L), medium (M) and small (S) based on the estimation form aerial photo interpretation.

4) Discharge volume of debris flow would be related to the potential of vertical and lateral erosion along the tributary. The length of each tributary has been classified into three categories, namely L (more than 5 km), M (1 ~ 5 km) and S (less than 1 km).

5) Damage potential of the settlement by debris flow has been evaluated. Since most of houses are standing on the slopes except around the exit of the tributary and along the channel course of the Jhelum River, direct damage potential by debris flow would be limited to the narrow area along the channel course of the river especially near to the confluence.

6) Evaluation results on this factor are same as those on the factor 5).

7) Damage potential of bridges by direct impact of debris flow has been evaluated. Bridges located near to the confluence or within around 2 km downstream of the confluence to the Jhelum River are estimated to be dangerous.

8) In case that the width of the channel course of the Jhelum River is narrow and alluvial fan area along it is small, debris flow can create channel blockage. Possible collapse of the debris mass at the blockage section is a certain hazard to downstream areas.

A large number of slope failures which occurred on the terrace cliff slopes as well as mountain slopes seem to have increased the unstable debris materials on the riverbeds of the tributaries. Those unstable debris materials were supplied mainly to the right bank tributaries and relatively few to the left bank tributaries in spite of steepness of the riverbeds. Six among seventeen right bank tributaries are evaluated to be highly hazardous and nine tributaries are moderately hazardous. On the contrary, nine among twenty-one left bank tributaries are evaluated to be moderately hazardous.

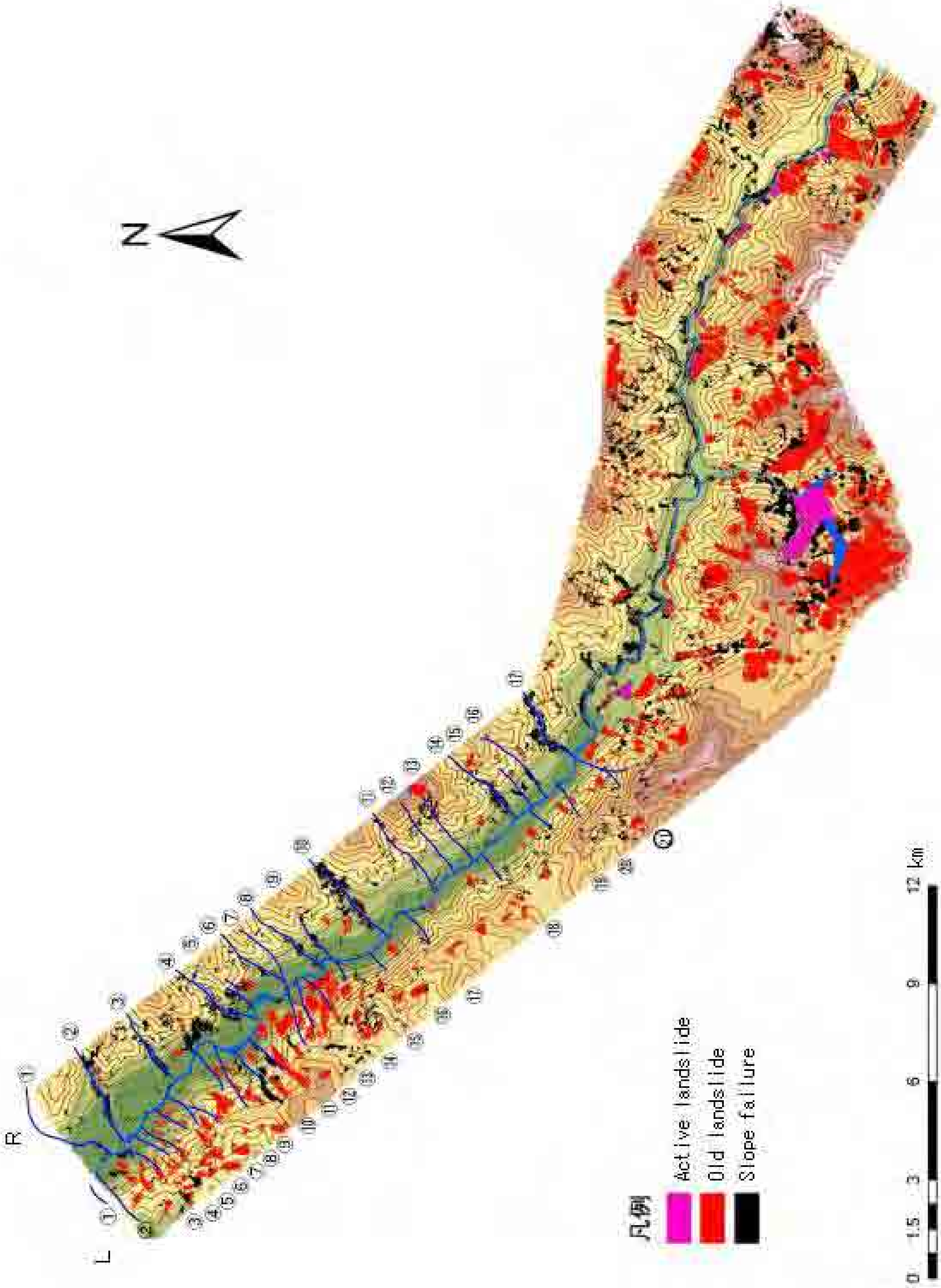


Figure 3.8 1 Right and left bank numbered tributaries of the Jhelum River

Table 3.8.1 Evaluation of debris flow risk along the Jhelum River

NO.	Existence of Jisuberi and Hokei(New)					Gradient (> 3°)	Sediment volume	Length of torrent	Topographical Setting	Houses		Cultivated land		Bridge
										torrent confluence	D/S	torrent confluence	D/S	
Remarks	Jisuberi ・F:Few ・M:Many		Hokei(New) ・Ter:Terrce Cliff ・Ms:Mount.slope ・UW:Upper Watershed				・L:Large ・M:Medium ・S:Small	・L:> 5 km ・M:1 km < , < 5 km ・S:< 1 km	・Se:Slope erosion ・Ter.dc:Terrace down Cutting ・fan:Alluvial fan	・F:Few ・M:Many		・L:Large ・S:Small		
	Old	New	Ter	Ms	UW									
Right bank														
R-1	×	×	S	×	×	○	M	L	Se	×	F	×	×	○
R-2	F	F	L	S	L	○	L	L	Ter.dc(H,L_1)	F	F	×	×	○
R-3	×	×	L	S	S	○	L	M	Ter.dc(H,L_2)	M	M	S	L	○
R-4	F	×	L	M	L	○	L	L	Ter.dc(H),fan	F	F	×	L	×
R-5	×	×	×	M	S	○	S	S	fan(L_2)	M	×	S	×	×
R-6	×	×	S	×	×	○	M	M	Ter.dc(H_2),fan(L_3)	M	F	L	S	×
R-7	F	×	M	×	S	○	M	M	Ter.dc(H),fan(L_3)	M	F	L	S	×
R-8	F	F	S	M	S	○	S	L	Ter.dc(H)	×	M	×	S	×
R-9	F	×	S	M	S	○	M	M	Ter.dc(H)	M	M	×	S	×
R-10	F	×	L	M	L	○	L	L	Ter.dc(H)	×	F	×	S	○
R-11	F	×	S	S	M	○	M	M	Ter.dc(H)	F	F	S	S	×
R-12	×	×	S	S	S	○	S	M	Ter.dc(H)	M	M	S	S	×
R-13	F	×	S	S	M	○	M	M	Ter.dc(H)	M	M	S	L	○
R-14	F	×	L	×	×	○	L	L	Ter.dc(H)	F	M	×	S	×
R-15	×	×	×	×	×	○	S	S	fan(L)	F	×	S	×	×
R-16	×	×	S	×	×	○	S	M	fan(L_2)	×	×	S	×	×
R-17	F	×	L	L	×	○	M	L	Ter.dc(H)	×	×	×	S	×
Left bank														
L-1	F	×	×	×	×	○	S	S	Se	F	×	S	×	×
L-2	F	×	×	×	×	○	S	S	Se	×	×	S	×	×
L-3	F	×	×	×	×	○	S	M	Se	×	×	×	×	×
L-4	×	×	×	×	×	○	S	M	Ter.dc(H)	×	×	×	×	×
L-5	F	×	×	×	×	○	S	M	Ter.dc(L_2)	×	×	×	×	×
L-6	F	×	×	×	×	○	S	M	Se	×	×	×	×	○
L-7	F	×	×	×	×	○	S	M	Ter.dc(L_2)	F	×	×	×	○
L-8	F	×	×	×	×	○	S	S	fan(L_1)	F	×	S	×	×
L-9	F	×	×	×	×	○	M	M	Se	×	×	×	×	×
L-10	F	×	×	×	×	○	S	M	Se	×	×	×	S	×
L-11	F	×	×	×	×	○	S	S	Se	×	×	×	×	×
L-12	F	×	×	×	×	○	S	M	Se	F	×	×	×	○
L-13	F	×	×	×	×	○	M	M	fan(L_2)	F	×	S	×	○
L-14	F	×	×	×	×	○	S	M	Se	×	×	×	×	×
L-15	×	×	×	×	×	○	S	S	fan(L_3)	×	×	×	×	×
L-16	F	×	×	×	×	○	M	S	fan(L_3)	F	×	S	×	○
L-17	×	×	×	×	×	○	S	M	fan(L_1)	F	M	S	S	×
L-18	×	×	×	×	×	○	S	S	fan(L_1)	F	×	S	×	○
L-19	×	×	×	×	×	○	S	M	fan(L_4)	F	×	S	×	×
L-20	×	×	×	×	×	○	S	M	fan(L_3)	M	×	S	×	○
L-21	×	×	×	×	×	○	M	M	fan(L_1)	M	×	S	×	×

3.9 Geological hazard assessment of the candidate sites of satellite towns of Muzaffarabad

3.9.1 Introduction

AJK government plans to make new satellite towns of Muzaffarabad along the Jhelum Valley in order to accommodate future increasing populations. On request from AJK, seven candidate sites (number 1 to 7 in Figure 3.9.1) were investigated from the view points of geology and geomorphology by using satellite images and maps made from the images. The satellite images used were taken by IKONOS with a resolution of 1 m. The maps used were made with scales of 1:10,000 and 1:25,000. Most of the sites are located on river terraces. All of them fit to residential areas and, if some areas are susceptible to debris flows, slope failures, and landslides, they are appropriately treated. The results are summarized in Table 1, and some comments on concerning issues common to them are described as follow.

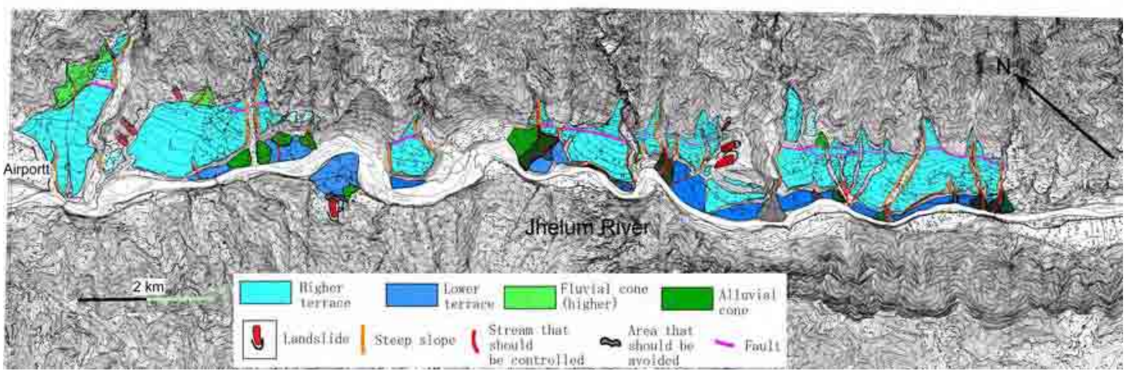


Figure 3.9.1 Locations of the candidate sites for new satellite towns (number 1 to 7)

Legends are the same with those in the following figures. Contour interval is 10 m.

(1) Outline of the geology and geomorphology

The area shown in Figure 3.9.1 is underlain by the Miocene Murree Formation consisting of alternating beds of sandstone and mudstone as bedrock, which is covered by Quaternary terrace and fluvial cone deposits. Along the Jhelum River, river terraces are developed particularly on its right bank; higher and lower terraces are widely developed as shown in Figure 3.9.1. The higher terraces are 50 to 100 m high above the Jhelum River and the lower terraces are several to 30 m high above the Jhelum River. The lowermost terrace is thus close to the river in elevation. They are fluvial cones along with the terraces; some are along the upper peripheries of higher terraces and some are on lower terraces with current riverbeds on them. The higher terraces have steep terrace scarps, some of which were steepened by slope failures during the earthquake. Many landslide bodies were observed on slopes in the surrounding areas and some landslides are located near candidate sites as is seen in Figure 3.9.1.

An earthquake fault, Balakot-Bagh Fault (Kaneda et al. in preparation), appeared during the 2005 Northern Pakistan Earthquake along the right bank of the Jhelum River, near the mountain-side edges of the higher terraces as is shown in Figure 3.9.1. The fault accompanied vertical separation up to 3.7 m in the area of Figure 3.9.1 (Kaneda et al. in preparation). The recurrence interval of this fault is estimated to be about 2000 to 3000 years from the trench investigation in Muzaffarabad, so this fault might not move in near future and the reactivation of this fault was not taken account in this paper.

Table3.9.1 Summary of the investigation results for each candidate site.

Site number	General comments	Concerning points	Recommendation
General	Planned sites are mainly on terrace surfaces, which are generally stable.	Earthquake fault appeared along the right bank of the Jhelum River, but it might not move in near future.	
		Some of the lower terrace surfaces are very low and might be immersed in water by flooding of the Jhelum River.	Check the expected flood height of the Jhelum River.
		Some of the terrace scarps have failed during the earthquake and the terrace surfaces near the scarps may have been affected.	Check whether cracks exist or not near the edges of the terrace surfaces. The area to be used must have enough distance is necessary from the terrace edges. Current inclination of stable terrace scarps could be used to determine the distance.
1	A terrace surface and an old fluvial cone in higher elevations are planned to be used.	There are three slide bodies to the north and to the east.	Make it sure that they are slides in the field and take some distance from the toe of the slide. For example 50 m.
2	A terrace surface and a small alluvial fan are planned to be used.	There are two slide bodies on the western slope.	Take some distance from the toe of the slide. For example 50 m.

Site number	General comments	Concerning points	Recommendation
3	A terrace surface offset by the fault are planned to be used.	Distance from the edge of the terrace.	See the general comment.
4	Two terrace surfaces are planned to be used.	There is a large alluvial cone in the northern part. The alluvial cone has many temporarilly abandoned channels, suggesting that the stream easily change its channel.	Avoid the alluvial cones or make some works to limit the flow. Some of the existing houses are recommended to move out.
5	Two terrace surfaces are planned to be used.	There is a large alluvial cone in the northern part. The stream seems to easily change its channel.	Avoid the alluvial cones or make some works to limit the flow.
6	Two terrace surfaces are planned to be used.	There are two alluvial cones on the lower terrace, in which southern one is large and present southern stream wall on it is only 3 or 4 m high and could be overtopped by debris flows.	Avoid the alluvial cones or make some works to controll the flow
7	Two terrace surfaces are planned to be used.	There are three alluvial cones on the lower terrace and two southern ones are large and show the evidence of previous debris flow. Middle one has a natural levee on the right bank of the present channel, but it is not complete.	Avoid the alluvial cones or make some works to controll the flow
		Slope failures with rock fall are expected from the terrace scarp between the lower and higher terraces.	Make some criteria to bound the safe area and/or make some works to prevent the debris movement Angles of a line connecting the end of failure deposits and the top of the source area could be used to determine it.

3.9.2 Concerning points and suggestions

(1) Debris flows:

Sites from 4 to 7 have alluvial cones, where recent debris flows came down (Figure 3.9.2). Particularly, site 4 has the largest cone on which many currently abandoned channels. The channel wall heights in these alluvial cones are not high enough, so some consideration should be made, including stream control by concrete walls or just avoiding the alluvial cones.

Figure 3.9.2 Debris flows in the candidate sites.

Upper left: No. 4; Lower left: No. 5; Upper right: No. 7; Lower right: No. 6 (NW end, looking to SE). These should be avoided.

(2) Failures of steep terrace scarps:

All sites except for site 2 have steep terrace scarps, below which lower terraces are planned to be used. A slope failure of the scarp was seen at site 7; rock debris flowed down the slope and stone blocks scattered around on the lower terrace at the foot of the scarp. It is not possible to predict potential site of this kind of a failure, so it is to be recommended to make some criteria to set a safety area from the failure of the scarp. One option is to take account of angles to the edge of a terrace scarp. From the observation of the deposits by the failure at site 7, the depositional area can be divided into three: areas of massive debris, densely scattered debris, and sparsely scattered debris (Figure 3.9.3). Figure 3.9.4 is a cross section showing this idea on the basis of the data obtained at site 7. Forty two degrees was an angle connecting the edges of the scarp and the massive debris area in this case. Massive debris areas should be avoided but other areas may be protected by some kind of walls or nets. Collecting this kind of data would be helpful to set some criteria for safety.

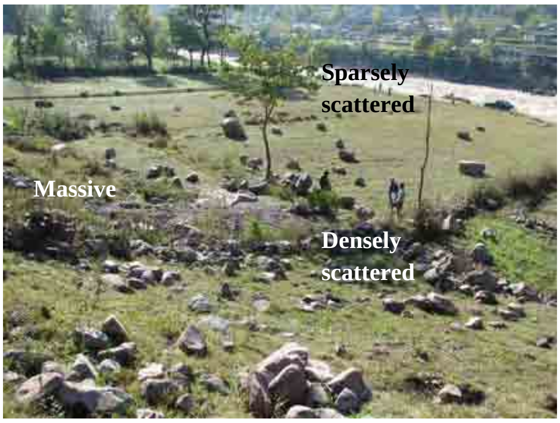


Figure 3.9.3 Slope failures on the terrace scarp of site 7.

The depositional area can be divided into three zones by the density of debris: massive area, densely scattered area, and sparsely scattered area. The inclination of the lines connecting these edges and the top of the source area could be used to delineate safety zones.

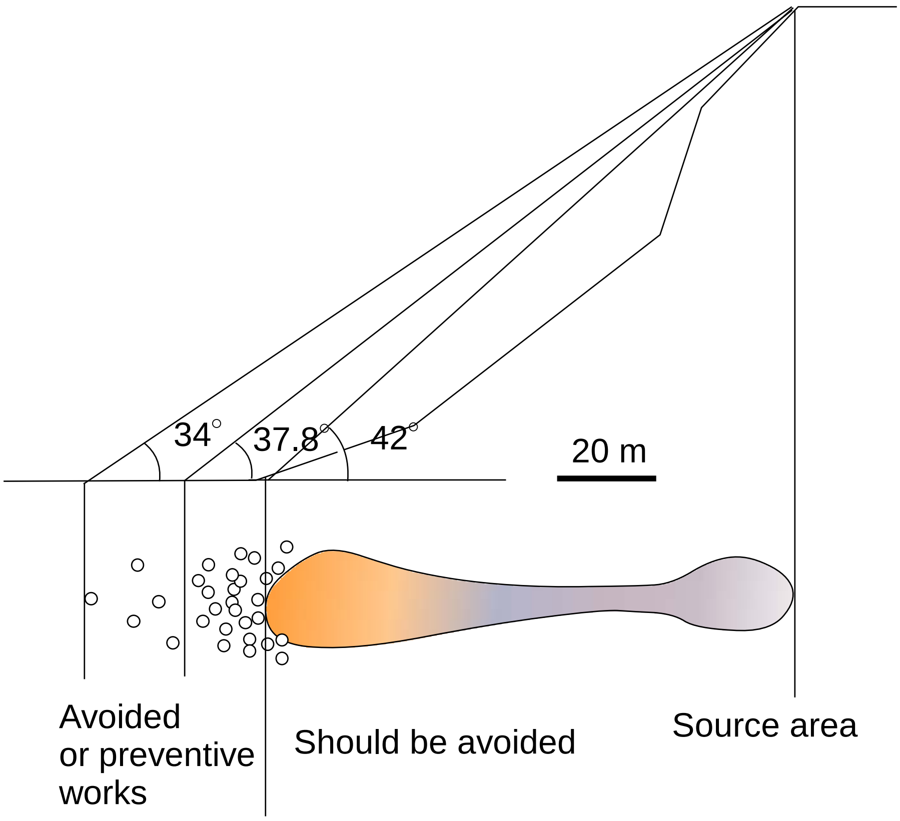


Figure 3.9.4 Cross section along the source and depositional areas of a slope failure at an edge of a steep terrace scarp at site 7.

(3) Distance from the edge of a terrace surface:

All sites will use higher terraces surrounded by steep terrace scarps, which failed in some parts by the earthquake. Careful examination should be made whether cracks are made or not near the edges of the terraces. For the safety, it is to be recommended to take some distance, security fringe, from the edges of the terraces. This distance could be determined by the stable inclination (maybe around 40˚) of the scarps. Figure 3.9.5 shows an idea to set a security fringe from the edge of a terrace above a steep scarp. Draw a line with an inclination of long-term stable terrace scarp from the foot of a steep scarp and obtain an intersection point with the terrace surface. The area between the terrace edge to the intersection could be a security fringe.

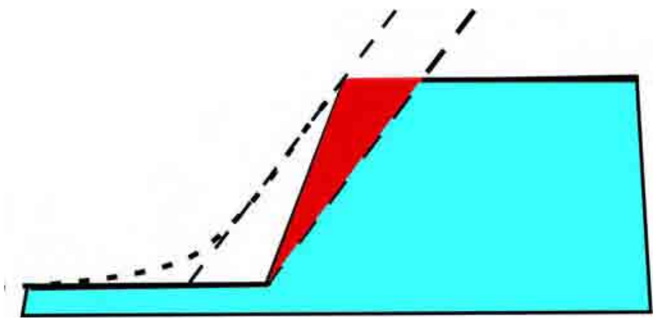


Figure 3.9.5 Over steepened terrace scarp and stable terrace scarp around the Muzaffarabad airport (above) and a schematic sketch for the setting of security fringe. (See text for the detail.)

(4) Landslide on nearby slopes:

Sites 1 and 2 have slide bodies on nearby slopes of the terraces. I recommend not using the edges of the terraces and take some distance from the toe of the slides, for example 50 m. Anyway, the activity of these slides should be evaluated by examining cracks, tilted trees, water conditions, and so on. I do not think this is a crucial issue to these sites 1 and 2.

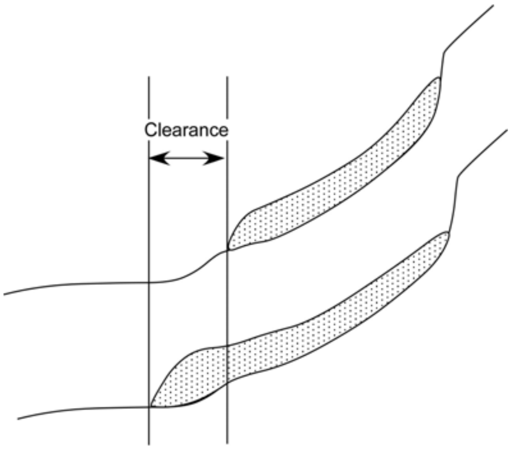


Figure 3.9.6 Damaged area near the toe of a landslide occurred in February, 2006 in Muzaffarabad (upper left) and the schematic sketch showing the necessity of clearance in front of the toe of a slide (upper right).

Lower left: Looking to the site No. 3 from the landslide above.

(5) Elevation of lower terraces:

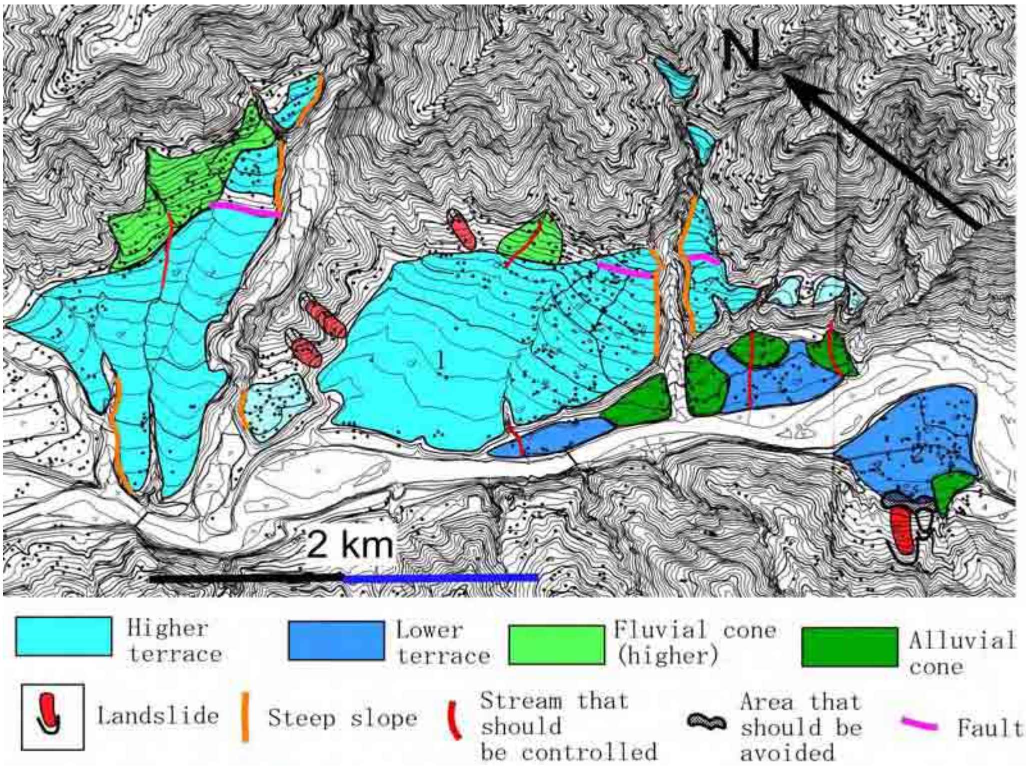
Some lower terraces may be too low and susceptible to flood of the Jhelum River, so the elevations of the lower terraces and the high water level of the Jhelum should be compared.

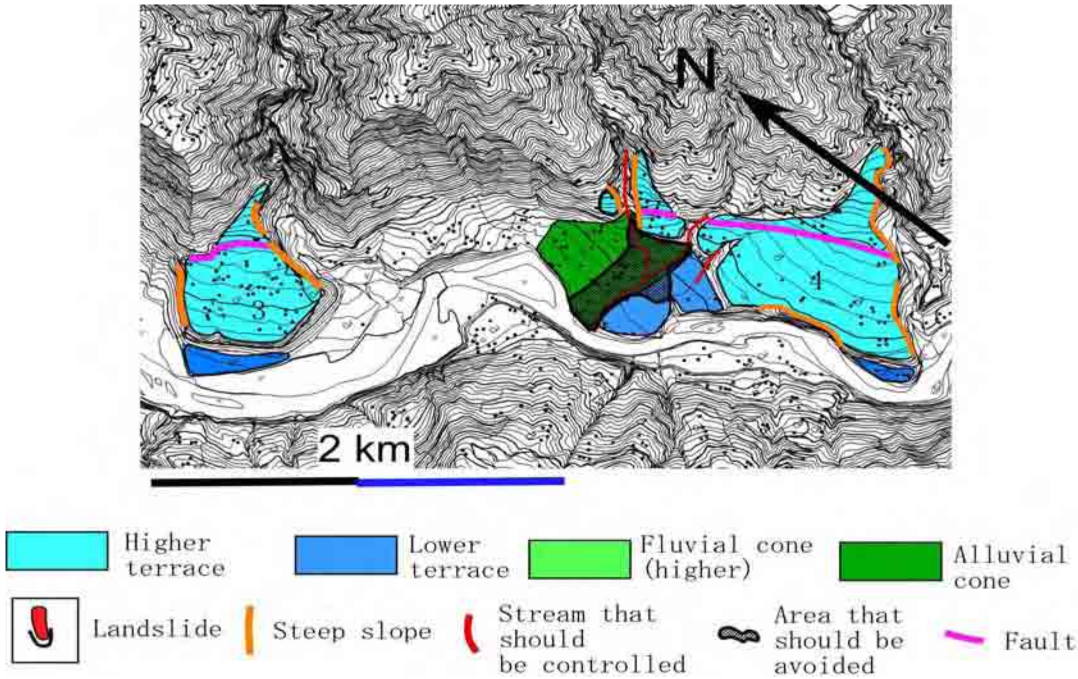
3.9.3 Concluding remarks

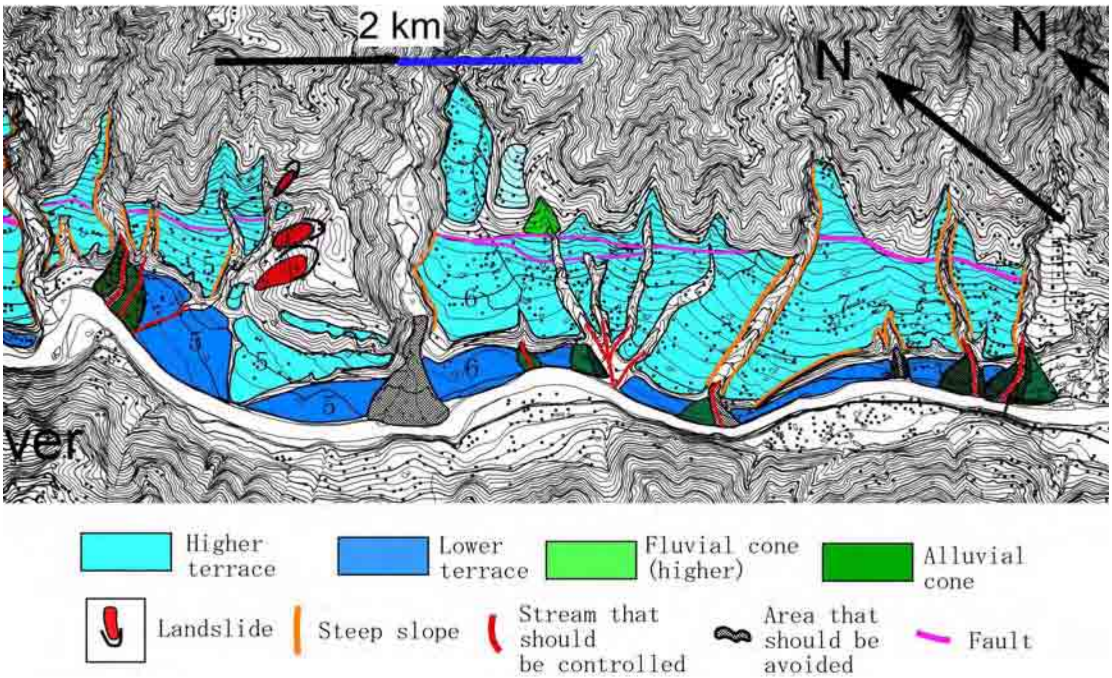
From the field investigation and the interpretation of satellite images, most of the candidate sites are safe if some considerations or countermeasures are made for limited dangerous areas. Flat areas nearby the Jhelum River are mostly terraces and similar issues described above are expected. It is to be recommended that detailed investigation will be made for the listed sites as well as neighboring potential sites.

This study was made in corporation with the Geological Survey of Pakistan.

Reference: Close up of the geomorphological classification map.




N
2 km
Higher terrace
Lower terrace
Fluvial cone (higher)
Alluvial cone
Landslide
Steep slope
Stream that should be controlled
Area that should be avoided
Fault


2 km
N
N
ver
Higher terrace
Lower terrace
Fluvial cone (higher)
Alluvial cone
Landslide
Steep slope
Stream that should be controlled
Area that should be avoided
Fault

3.10 Seminar and workshop

(1) Seminar

Title: Slope Disaster Management －Envisioning Safer Pakistan Disaster Risk Reduction for Steady Recovery From 8th Oct. 2005 Earthquake Damage－

The seminar on slope disaster management was held under the auspices of JICA and Study Team. in association with Japan Landslide Society and Geological Survey of Pakistan in Islamabad (GSP) on December 26, .2006.

This seminar aims to transfer the technology on disaster reduction to the Pakistan engineers and to report the results of investigation on the slope disasters by the Northern Pakistan Earthquake.

After the greetings from Mr. Kaibara, Resident Representative of JICA Pakistan Office, Mr. S. A. A. Khan, Prime Minister of State of Azad Jammu Kashimir and Mr. M. S. Siddiqui, Federal Minister of Communication Prof. Chigira from the Japan Landslide Society made a key note speech for the hazards of the satellite city of Muzaffarabad （Photo）.

In three sessions 1) Slope hazard and slope disaster management, 2) Disaster risk reduction for steady recovery from the 8th October 2005 earthquake damage, 3) Envisioning safer Pakistan slope disaster reduction) ten presentations and discussion were made (Photo 3.10.1, 3.10.2).

Photo 3.10.1 Prof. Chigira

Photo 3.10.2 Participants

Importance in detection of the slopes with landslide topography by air photo interpretation and those with shallow slope deformation (Prof.Yagi), practical use of the slope disaster prevention countermeasures that had been used under the technical cooperation of Japan and Nepal (Prof.Higaki), necessity of construction of early warning system were pointed out in the presentations.

After the presentation, it was discussed that the disaster prevention countermeasure planning in case of the use of current road route, monitoring of the influence of the landslides and slope failures to river aggregation. It was also pointed out that the land use of the slopes in a stricken area of the 2004 Mid-Niigata Earthquake in Japan are similar to that of the Northern Pakistan Earthquake and the characteristics of slope disasters were common (Prof.Marui). This means that our experiences of slope disasters by an earthquake and adopted disaster prevention measures in Japan are useful to the recovery of Pakistan from the earthquake damages.

Mr. Kishino, Minister of the Japanese embassy emphasized the significance of cooperation on the earthquake disaster recovery to Pakistan in his greetings of closing ceremony and the flowing points as well.

1) Awareness creation
2) Empowerment of local community
3) Human resource development
4) Enhancing disaster prevention technology to developing country
5) Use of local materials
6) Sharing the experience

He also highly evaluated the significance of this seminar.

100~120 participants consisting of engineers, administrators, researchers, etc. could discussed for all day thus making the seminar white-heated. This seminar was taken up by mass media. This seminar could provide a starting point for making the society resistant to slope disasters in Pakistan.

(2) Workshop on aerial photo interpretation of landslides

A lot of landslides have been induced by the 2005 Northern Pakistan Earthquake along the Jhelum River and the Nielum River in AJK, Pakistan. Since landslides are often reactivated and also induce slope failures (Hokai) and debris flows, identification of the slopes formed by landslide is a fundamental process for landslide hazard management as well as rehabilitation, reconstruction after the earthquake disaster. Aerial photo interpretation is the most appropriate way to detect such slopes, though basic knowledge of geomorphology and landslide reconnaissance survey is required.

The workshop on aerial photo interpretation of landslides was held to transfer basic techniques and its theoretical background at GSP Islamabad office by JICA and Study Team on December 21, 22 and 23, 2006. 19 Nos. of the officers consisting of 13 person from GSP and 4 from NHA and 2 from University participated in it. Eighteen stereoscopes of which three sets have been granted to GSP were prepared from Japan.

Photo 3.10.3 Lecture by Prof. Yagi

Photo 3.10.4 Workshop on aerial photo

Basic principles of aerial photo interpretation of topography were explained by Prof. Yagi. Then, river terraces were interpreted as the first step to identify geomorphological units and mapping them. The second step was to identify a unit landslide slope consisting of head scarp and moving body. Some sets of aerial photos and contour maps were prepared from Japan by Prof. Yagi. At this stage many participants became confused in identification scale and they had focused on surfacial slope failure instead of deep-seated landslides. Field inspection of landslide should have been conducted after the lecture for better understanding of slope failure (Hokai) and landslide (Jisuberi). However on the third day all the participants could identify scarps, cracks caused by landslides. Thus it enables them to make distribution map of landslide slopes.

After this training an expert system to evaluate landslide hazard by using AHP (Analytical Hierarchy Process) method was explained by Prof. Higaki.

The final stage of the workshop aimed to interpret the earthquake induced landslides from the IKONOS satellite images of the Northern Pakistan Earthquake affected area which were processed in Japan. Since the topography of the Jhelum River catchment is rather complex, this was not the easy task for the participants. However they could easily identify the area of landslide damming near Dandbeh.

After these stages, the certificate of participation in the workshop was distributed to the participants from the director of GSP.

(3) Second Workshop

Title: Monitoring, Prediction and Mitigation of Landslide Hazards

The second workshop on Monitoring, Prediction and Mitigation of Landslide Hazards was held under the auspices of JICA and Study Team. in association with NHA and GSP on January 28 and 29, .2008.

This workshop aims to transfer the technology on monitoring, prediction and mitigation of landslide hazards as well as to spread the guideline for slope inspection for maintenance of road-side slopes prepared by Study Team.

After the welcome address by Mr. Shahid Majeed, Member of Operation, NHA and the opening remarks by Mr. Takao Kaibara, Resident Representative, JICA Pakistan Office, Dr. M. Ogasawara, JICA Monitoring Mision, presented made a key note speech “Role of geology for landslide hazard mitigation”.

In four technical sessions; 1) Paleoseismic evidence of surface rupture of the 2005 Kashimir earthquake in Pakistan, 2) Eartquake induced geo-hazards in Kashmir and NWFP, 3) Slope inspection works; Introduction of “A guide of slope inspection for road maintenance”, 4) Road disaster management, Mr. Y. MOMOSE, JICA Study Team briefly introduced the guideline and Mr. S. Takahashi present, JICA Expert, lectured on the Emergency Monitoring and Information System under use in Japan in the Session 3 and 4 respectively.

Mr. Takeo Kaibara

Dr. M. Ogasawara

Mr. Y. Momose

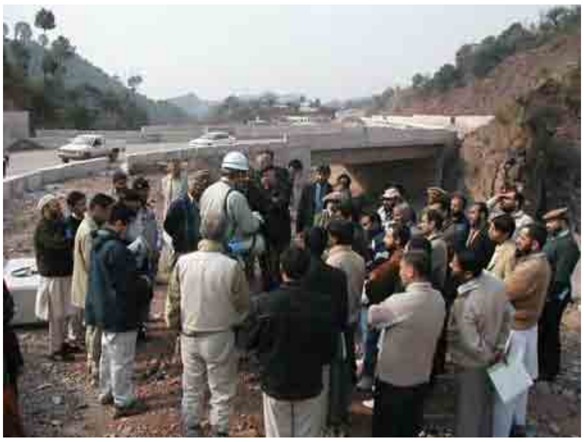
Mr. S. Takahashi

Photo3.10.5 Workshop on Monitoring, Prediction and Mitigation of Landslide Hazards

1st day (28th January 2008)

The second day (29 January) workshop aiming to train "how to inspect slopes" by excise on actual filed was held along the National Highway N-75 (Satra Mile to Lower Topa Section).

Mr. Y. MOMOSE briefly introduced and explained the "know-how" and techniques of inspection and evaluation of slopes using the form of Slope Inspection Sheet and Mr. S. Takahashi also introduced the temporary emergency countermeasure for slope failure using "Ton-Pack".



Mr. Y. Momose

Mr. S. Takahashi

"Ton-Pack"

Photo 3.10.6 Workshop on Monitoring, Prediction and Mitigation of Landslide Hazards

2nd day (29th January 2008)

3.11 Preparation of a Guide of Slope Inspection for Road Maintenance

3.11.1 Recommendation for Steady Recovery of Road System from 2005 Earthquake Damage

An earthquake measuring 7.6 on the Richter scale struck the northern areas of Pakistan and India on October 8, 2005. Numerous landslides, which mostly became active after the earthquake as mentioned in previous sections, have posed considerable hazards to the people and their property. Risk reduction of landslides is an urgent need for the reconstruction of the severely damaged area. For this dangerous condition, it is necessary to take drastic measures, such as execution of landslide countermeasures and realignment of existing road in the landslide affected sections.

However, these drastic measures will require a lot of time and cost, and it is impossible to treat all landslide-prone slopes. The earthquake affected road should suffer landslide disasters particularly during wet season. Road maintenance works are therefore recommended to be carried out efficiently and effectively for the long term.

In view of circumstances mentioned above, the following actions are recommended for risk reduction of landslides on the road side slope damaged by October 8th 2005 Earthquake.

(1) Efficient and Effective Road Maintenance based on Road Slope Inspection

Risk reduction of landslides can be effected through effectual countermeasures based on slope inspections. Since slope stability is subject to many factors such as, topography, geological structure, soil/rock type, surface and ground water conditions, and effectiveness of protection work, the accuracy of the results of slope inspection shall affect the outcome of the rehabilitation works to be applied. Furthermore, even an appropriate designed and constructed slope must deteriorate through weathering and erosion, and it is therefore hard to understand a long-term perspective about slope stability at the design stage and even at construction stage. Slope inspection also plays an indispensable follow-up maintenance to keep a proper function of the traffic and to enhance its safety.

(2) Capacity Building of Road Maintenance Stuff

There are few specialized engineers for slope stability in Pakistan. The dissemination of an essential knowledge to the staff in charge of the road maintenance in Pakistan is essential to risk reduction of landslides.

(3) Introduction of Quick Response and Emergency Measures against Landslide

An appropriate and timely measure can prevent recurring landslides and help in the rehabilitation procedure. Keeping out water by plastic sheets and installation of sand bags at the toe of the slope are effective to mitigate slope disaster as well as economical.

3.11.2 Necessary of Preparation of Slope Inspection Guide

In Pakistan, road maintenance works against landslides have been carried out on a routine or a periodic basis and the knowledge of slope protection techniques has been accumulated accordingly.

However, there is no manual or standards for slope inspections, even though its importance is recognized by the staff in charge of road maintenance works in NHA and Public Works Department of AJK (hereinafter referred to as PWD). Insufficient measure against a landslide due to the lack of necessary field data causes frequent landslides, which consequently impose financial strain in road maintenance.

For risk reduction of landslides, it is therefore essential to prepare the guide of slope inspection and to provide an assistance of capacity building of slope inspection for the staff in charge of road maintenance works.

3.11.3 Purpose of the Guide of Slope Inspection

The Guide aims the risk reduction of landslides through the development of the slope inspection for road maintenance. In view of circumstances in a lack of specialized engineers for slope stability, this Guide emphasizes the dissemination of an essential knowledge to the staff in charge of the road maintenance in Pakistan.

Furthermore, the Guide also covers emergency measures in a response to the urgent need of landslide risk reduction, since an appropriate and timely measure can prevent recurring landslides and help in the rehabilitation procedure.

3.11.4 Outline of the Guide of Slope Inspection

The Guide is comprised of two chapters, the first of which gives the basic concept of the slope protection and the scope of application of this Guide and the second chapter provides many lessons from the experiences of landslides.

The Guide is shown in attached Appendix A.

With respect to road maintenance, many of its concepts introduced in this Guide owes to "Road Association of Japan (1999), Highway Earthworks Series: Manual for Slope Protection", and many materials of the experiences of landslides are referred to "Slope

Inspection Guide Series I~III" published by Japan Highway Public Corporation (JH) in 1983, 1986 and 1989.

In addition to the references above, geological data and photographs of landslides and some mitigation measures against landslide on the existing roadside slope were obtained through the site inspections in collaboration with NHA and GSP (Geological Survey of Pakistan) from June 2006 to August 2007 covering two wet seasons after the earthquake.