"Our technological powers increase, but the side effects and potential hazards also escalate."

– Alvin Toffler

LANDSLIDE TRIGGERS 6

Landslides can have several causes, including geological, morphological, physical, and human but only one trigger (Varnes, 1978, Alexander, 1992). A trigger is an external stimulus such as intense rainfall, earthquake shaking, volcanic eruption, storm waves, or rapid stream erosion that causes a near-immediate response in the form of landslide by rapidly increasing the stresses or by reducing the strength of slope materials (Wieczorek, 1996). Therefore, the requisite short time frame of cause and effect is the critical element in the identification of a landslide trigger. Three important landslide triggers viz. *Rainfall, Earthquake Shaking and Anthropogenic Interference* are indentified in Mangti Landslide Environ; their influence on triggering landslides and threshold values along the TJRC are enumerated as under.

RAINFALL

Meteo-climatic factors are the most relevant for the triggering of slope instabilities. Both shallow and deep-seated landslides can be triggered by rainfall, with different frequencies, both in time and space, and under the effects of different types of storms. Shallow landslides, especially soil slips and debris flows, are triggered by intense short-duration rainfall, whereas landslides in clayey soils and deep-seated landslides are more sensitive to events of long and moderate intensity. As a consequence, rainfall analysis is the most frequently adopted approach for forecasting the occurrence of such phenomena (Crosta, 2004).

Effects of rainfall and its manifestations like rapid snow melting, water level change, stream flooding and rapid stream erosion causing landslides have been studied globally. There exists well documented studies that have revealed a close relationship between rainfall duration – intensity and activation of landslides viz. Ellen et al. (1988), Gryta and Bartholomew (1989), Simon et al. (1990), Larsen and Sanchez (1992), Sandersen et al. (1995), Iverson (2000), Mihalic et al. (2003), Siddle (2006) and Scottish Executive (2006).

Further role of rainfall as triggering factor has been well established in case of recently occurred landslides in India viz. Malpa Debris Flow (Pal et al., 1998) and Ukhimath Debris slide near Rudraprayag (Bist and Sah, 1999).

Precipitation coupled with other climatic parameters is considered to be the most significant triggering factor in slope movements. In the study area rainfall and other climatical data are monitored at the NHPC Meteorological Observatory situated near Dhauliganga Hydel Project at Chirkila, which is operational since 1980.

Although the meteorological observatory is functional since 1980, however the daily rainfall data were obtained only for the period between 1997 and 2004. The Mangti Landslide is situated at about 22km away from this observatory and it being only station in this area hence, data collected from this observatory has been utilized to study the impact of rainfall on slope failure and to establish correlation with the rainfall and landslide incidences.

Further as the terrain is characterized by high order of relief variation, the rainfall distribution pattern shows considerable change from one valley to another river valley, therefore in order to obtain effective rainfall, a temporary rain gauge station near Mangti Landslide (Plate VI. 1) was established particularly for recording rainfall received during monsoon season, i.e., from June to September months.

Like other regions in India, the Himalayan region also receives its major rainfall during monsoon period ranging from mid-June to mid-September. Precipitation is also received during winter season in the form of snowfall with occasional light rains.

Plate VI.1 Field Photograph of Rain Gauge Placed Near Mangti Landslide

Study of rainfall distribution pattern for the period 1997 and 2003 suggests that major precipitation is received during July and August months with about 42 days as effective rainy days, i.e., > 10mm rain.

Histogram (Figure 6.1) depicting annual average rainfall pattern in the study area shows that except during year 1997, it has received more than 2000 mm precipitation and the average annual rainfall stands at 2232mm. Out of the total average precipitation received by the area almost 79.59% rain is confined to rainy season (Table 6.1). Wherein, average precipitation 620mm (37.37%) is received during July month followed by August 496mm (29.90%) and months of June and September each received about 16.39% of rain. Therefore, almost 67.27% of average annual rainfall is received by the study area during July and August months only.

Figure 6.1 - Bar Plots Showing Annual Rainfall Pattern, Mangti Landslide Environ

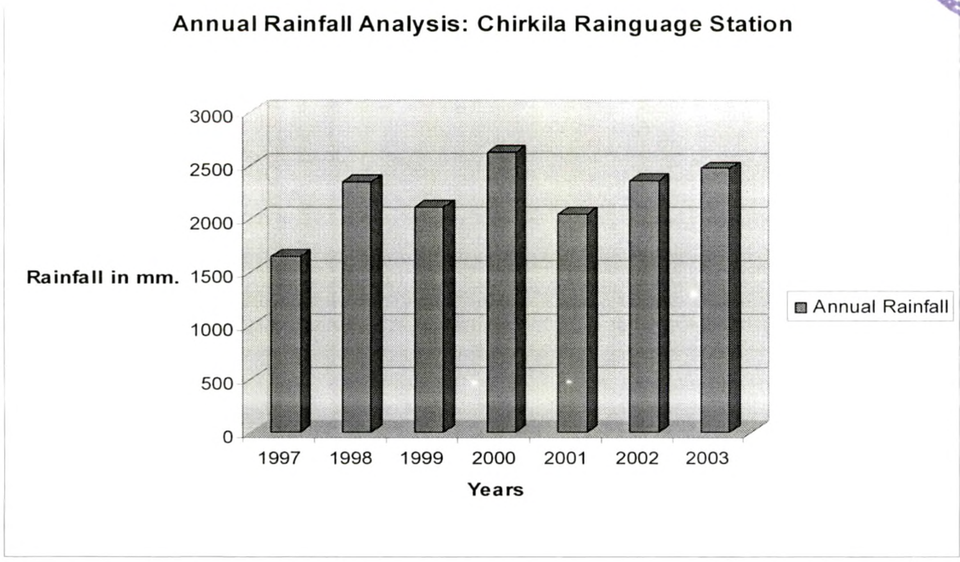


Table 6.1: Statistical Data on Rainfall Distribution Pattern and Observed Landslide Incidents: Mangti Landslide Environ

YEAR	Monthly Rainfall for Rainy Season (mm)				Total Rainfall of Rainy Season (mm)	Annual Rainfall (mm)	% of Rainfall During Rainy Season
	June	July	August	September			
1997	132.00	474.60	337.25	288.25	1232.10	1646.85	74.81
1998	374.00	506.00	651.25	300.50	1831.75	2350.75	77.92
1999	361.00	748.75	434.25	366.75	1910.75	2112.50	90.49
2000	396.25	837.50	618.75	190.25	2042.75	2628.25	77.72
2001	343.50	753.50	461.75	105.00	1663.75	2042.75	81.44
2002	179.75	518.50	639.25	408.25	1745.75	2367.75	73.73
2003	190.50	710.00	647.25	460.50	2008.25	2476.95	81.07
2004	189.13	411.82	179.55	56.38	836.88	-	-
Average Rainfall Pattern	270.77	620.08	496.16	271.99	1659.00	2232.26	79.60
Percentage of Rainfall Received During Rainy Season	16.32	37.37	29.9	16.39	-	-	-
Cumulative Landslides Recorded 2000-2004	34	103	79	63	-	-	-

Precipitation when infiltrates through the land surface depending on hydraulic characteristics of the slope mass material provides saturation to the media, that in-turn gradually builds up the pore water pressure and affects cohesion and overall shearing strength of the slope mass causing landslides.

This has already been elucidated that the TJRC is being developed and also maintained by BRDO. 144. The BRDO is also maintaining the record of the landslide incidences that are taking place along the route corridor, comprising information as, date of incidence, its dimensions, action taken etc. These well documented records are available from 2001 onwards. These recorded landslide incidences have been accounted for correlation with the rainfall events in the study area (Table 6.2) and detailed summary is presented as **(APPENDIX – 1).**

Careful examination of rainfall inputs received during monsoon period (June – September) and its correlation with the recorded landslide incidences show that majority of landslides (more than 90%) in the Tawaghat – Jipti Route Corridor have taken place during the months of June – September and predominantly during July – August months (Table 6.2) only. In all 293 landslide incidences have been recorded from the study area, out of which 116 (39.6%) landslides were recorded during the year 2004 alone. In that more than 50% **(58 nos.)** of landslides have been recorded during the month of July only. This extremely high recurrence of landslides in this particular month is attributed to an intense *Cloud Burst* experienced in the area on **18th July 2004**.

Rainfall triggering threshold has been analyzed using daily recorded rainfall and landslide incidences. It is found that whenever the study area has received 22mm rainfall or more, there has been a land slide incidence. Table 6.3 gives the details on monthly based rainfall events and recorded landslide incidences, which fairly fits well for series of landslide recurrences observed in the study area (Figure 6.2E-H).

Hence, the threshold value of rainfall, i.e., >22mm is derived based on the assessment of available historical information. However, with prolonged monitoring and recording of daily rainfall and landslide events would further help to refine the threshold value.

Table 6.2 - Landslide Incidences Along Tawaghat - Jipti Route Corridor

Data Source: 1. *Annual Landslide Report of BRO-GREF, Pithoragarh*
2. *Rainfall Data from NHPC, Dhauliganga Hydel Project*

Year	Month	Rainfall (mm)	Total Number of Landslides Occurred	Total Landslides in a Year
2000	June	396.25	17	32
	July	837.50	6	
	August	618.75	9	
2001	May	115.00	1	31
	June	343.50	5	
	July	753.50	18	
	August	461.75	7	
2002	April	93.00	1	32
	May	84.50	2	
	June	179.75	1	
	July	518.50	5	
	August	639.25	15	
	September	408.25	8	
2003	May	73.00	3	81
	June	190.50	NIL	
	July	710.00	16	
	August	647.26	26	
	September	460.50	37	
2004	April	-	1	116
	May	-	6	
	June	-	11	
	July	189.13	**58**	
	August	411.82	22	
	September	179.55	18	
			TOTAL	**293**

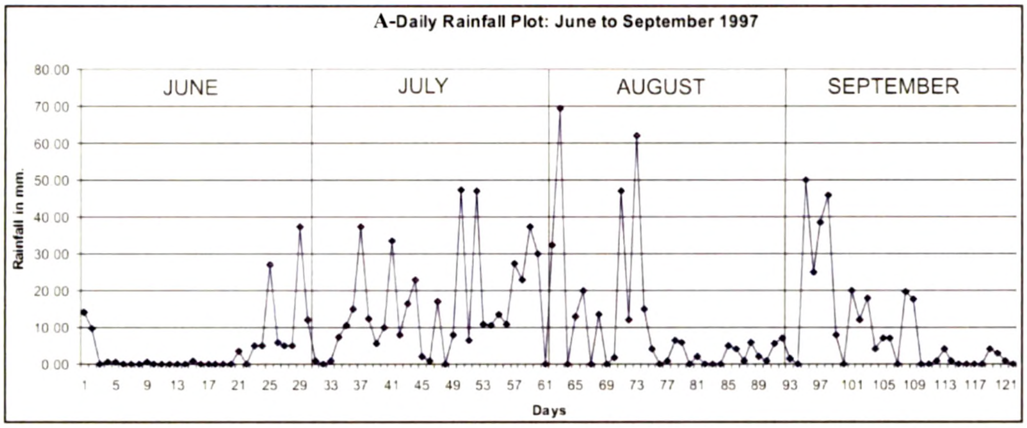
Histograms depicting annual recorded landslide events at an estimated threshold value of rainfall (> 22 mm) event clearly point to the gravity of the landslide problem along TJRC (Figure 6.3).

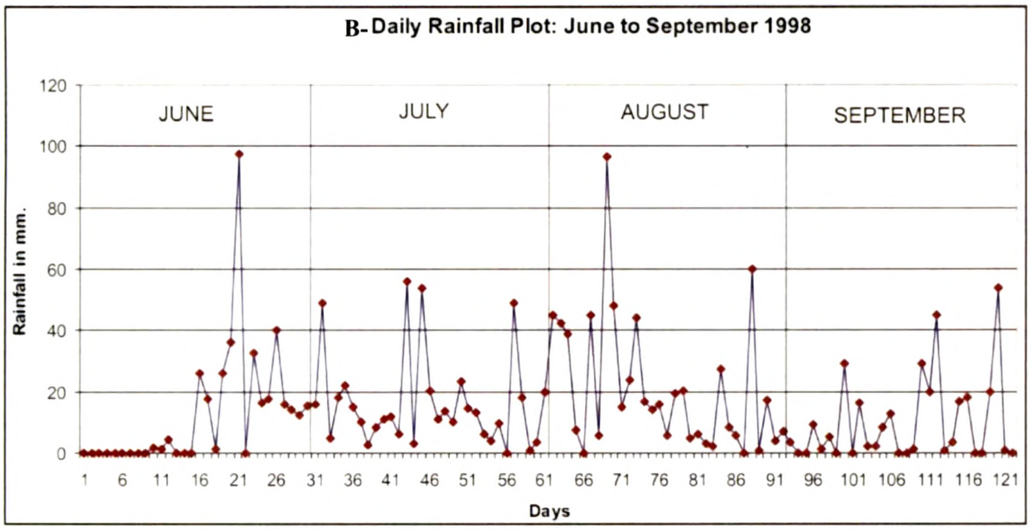
Table 6.3 - Rainfall - Landslide Incidences Correlation
Tawaghat - Jipti Route Corridor

Year	Number of Days Rainfall Recorded >22mm and Number of Landslide Incidences								Total Rainy days > 22mm	Total Landslide Incidences
	June		July		August		September			
	R	N	R	N	R	N	R	N		
2000	5	17	18	6	11	9	-	-	**34**	**32**
2001	4	5	11	18	8	7	-	-	**23**	**30**
2002	3	1	7	5	12	15	8	8	**30**	**29**
2003	2	NIL	13	16	14	26	8	37	**37**	**79**
2004	-	11	3*	58*	4	22	2	18	**9**	**98**

Note: * Intense cloud burst witnessed on 18th July 2004 resulting into innumerable landslides

Rainfall Event (**R**) in days > 22mm and Number of Landslide Incidences(**N**)





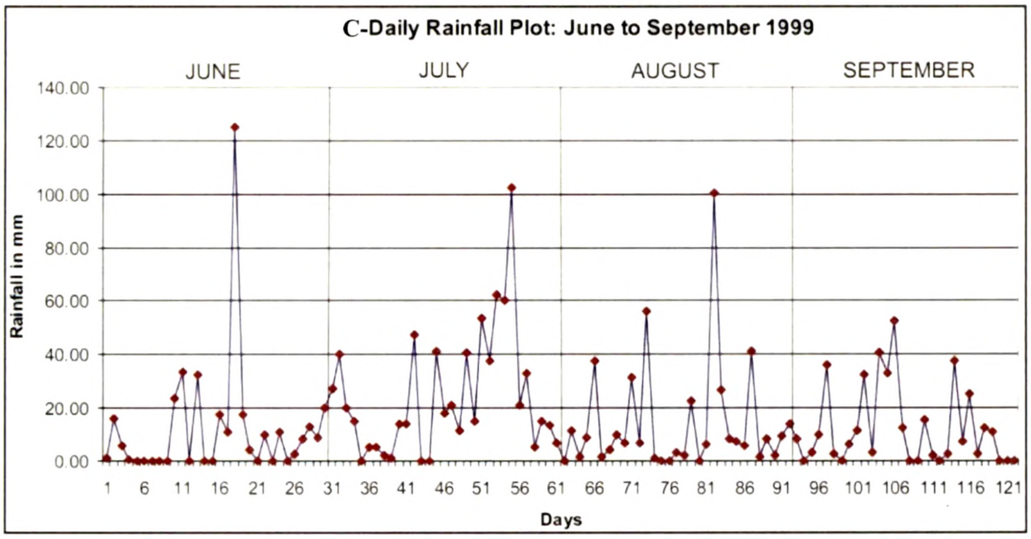
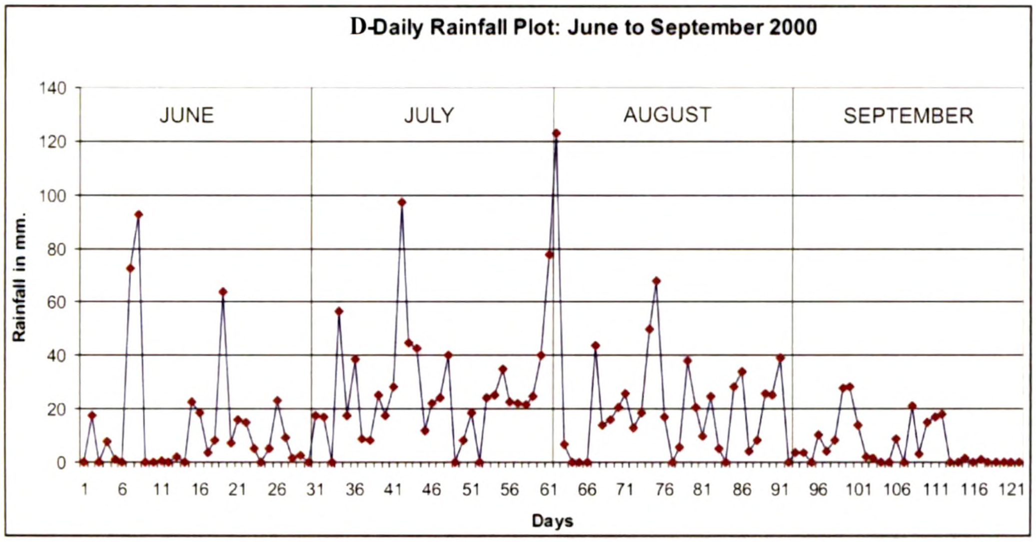
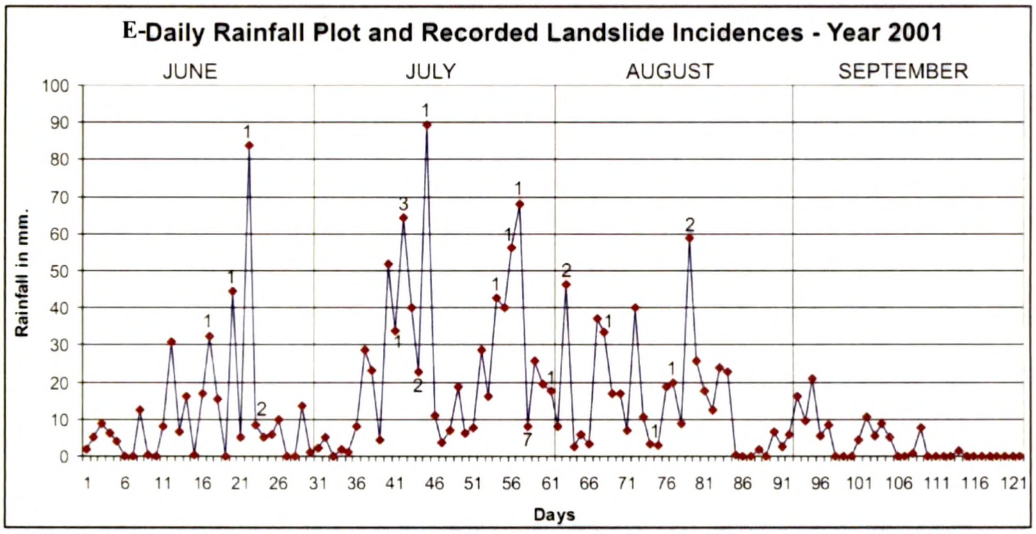
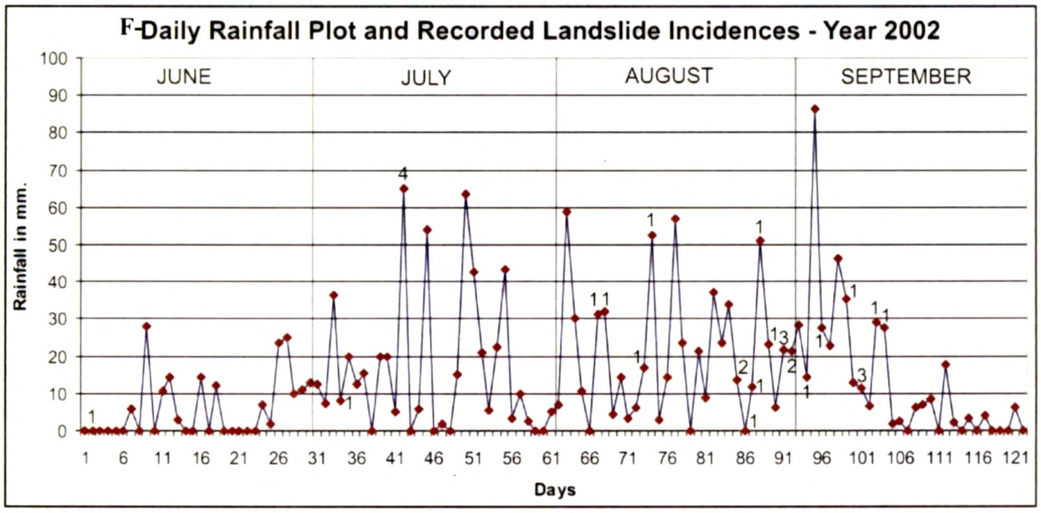


Figure 6.2 Continued......







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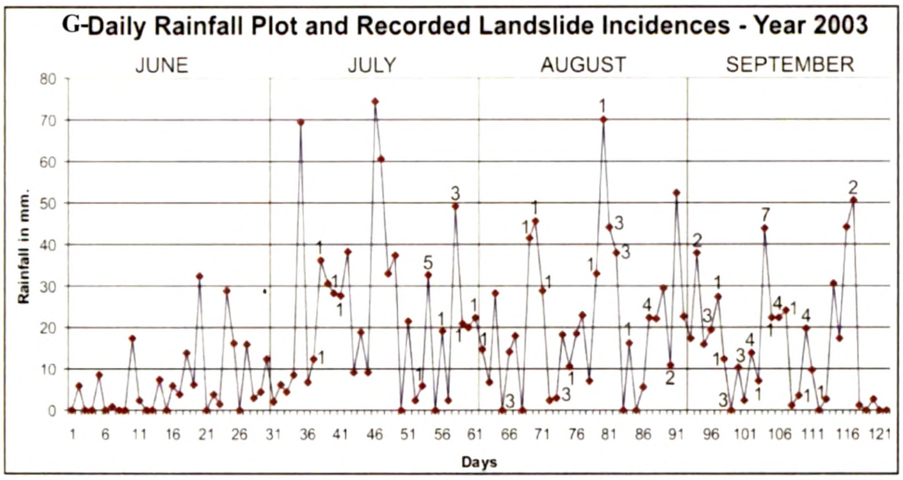


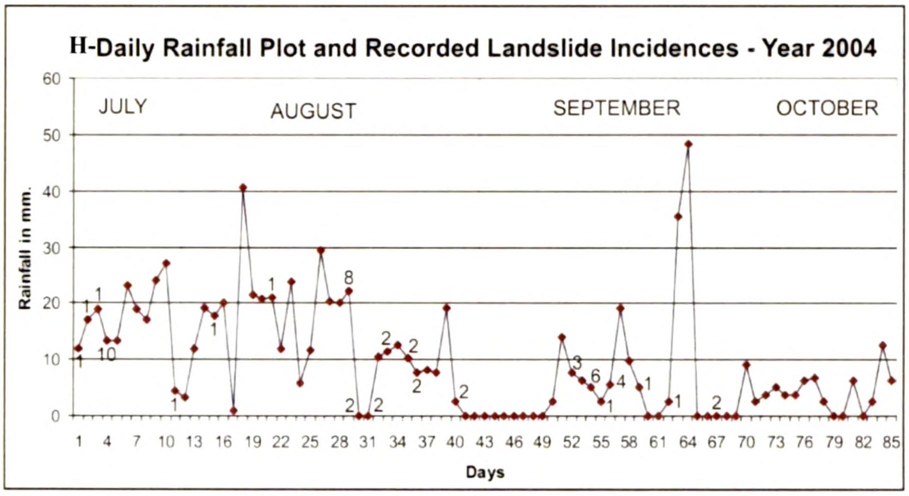


Figure 6.2 - Correlations of Observed Rainfall Hydrographs and Landslide Incidences, Mangti Landslide Environ

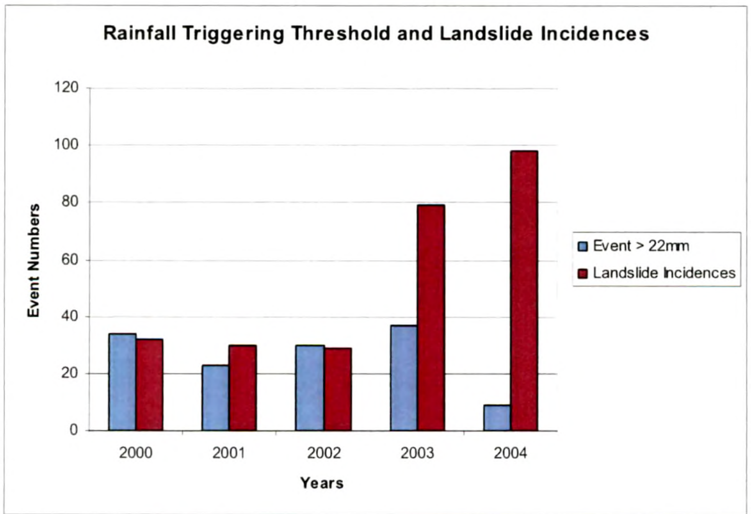


Figure 6.3 - Correlations of Rainfall Triggering Threshold and Landslide Incidences, Mangti Landslide Environ.

SEISMICITY

The destructive impact of earthquakes, in many parts of the world, is greatly enhanced by the triggering of landslides during or after the shaking. There can be little doubt that after the direct effect of structural damage due to the strong ground-motion caused by earthquakes, landslides are the most important consequence of earthquake shaking. This is indicated by many such documentary evidences published worldwide (Wen-Neng Wang, 2003; Ken-Jian Shou, 2003; Bommer 2002; Prestininzi, 2000; Wasowski, 2000 and many more). A prerequisite of an effective and realistic seismic risk mitigation programme is a quantitative assessment of the distribution and magnitude of this important collateral hazard. The assessment of the hazard of earthquake-induced landslides can be performed at different levels ranging from regional studies to the site-specific evaluation of individual slopes.

The fundamental framework on which the entire characterization of earthquake induced landslide activity is based on two basic parameters viz. the susceptibility of the slopes to earthquake-induced instability and a measure of the intensity of the earthquake shaking (Bommer, 2002). Landslides involving loose, saturated non-cohesive soils on low to moderate slopes commonly occur as a result of earthquake-induced liquefaction due to temporary rise in pore water pressure that reduces the shearing strength of the material. The earthquake induced landslide hazard can be measured in many ways, again reflecting a wide range of levels of sophistication. In the simplest approaches, the hazard is expressed as a binary function defining geographical limits within which landslides will be expected from an earthquake of specified magnitude and location. The most complicated approaches express the hazard in terms of the expected Newmark displacements of slopes that become unstable due to ground shaking (e.g. Wilson and Keefer, 1983).

Further to state that active seismicity in Himalayan domain is well accepted fact. The continuous collision between Indian and Eurasian plates is the reason for the high level seismicity in the Himalayan region. Seismo–tectonic model of the Himalaya postulated by Seeber, et al. (1981); comprises a subducting slab, the Indian Shield;

an over riding slab, the Tethyan slab; and a sedimentary wedge contained between and decoupled from the two converging slabs suggests that the active thrusts coincides with the subducting slab, wherein the fault between the subducting slab and the sedimentary wedge is termed as the Detachment. The movement associated with the subducting detachment slab below the over-riding sedimentary wedge is responsible for all the great Himalayan earthquakes. In the intermittent period between the great earthquakes, the Detachment remains aseismic and moderate magnitude thrust earthquakes occur in a narrow belt down dip from the Basement Thrust Front or in the deeper part of the MCT as it merges into the Basement Thrust.

Seismicity wise the Uttarakhand State and particularly its eastern part and adjacent Nepal Himalayan region is considered to be the most active. Historical account on seismicity has been collected from the Indian Meteorological Department (IMD) and U.S.G.S. Earthquake database for more than 200 years, i.e., 1803 – 2004 **(APPENDIX 2)**. Tele-seismically determined epicenters of this geographic domain (Figure 6.4) indicate that the majority of earthquake epicenters are located north of MBT. Also, recorded earthquake magnitude falls within the range of M5 – M7.

Along Indo-Western Nepal border region i.e. at Bajang the largest magnitude of earthquake reported so far is 7.5. Whereas, other regions in Himalayas have already recorded great earthquakes of magnitude >= 8. Due to frequent occurrences of moderate size earthquakes and on-going developmental activities of multipurpose projects, this region has acquired an added significance to study the natural hazards and prevent probable damages to the infrastructure, properties and lives.

Review of earthquake records points to the fact that this region is characterized by shallow focus earthquakes with their foci ranging from 05 – 93 km. The largest earthquake (M=7.5) in the region occurred on 28th August 1916 in Dharchula area. Seismic activity was diffused along the MCT and on a number of tear faults like Almora and Main Boundary Thrusts (Gupta & Srivastava, 1992). Further focal mechanism of earthquakes also supports predominantly of thrust faulting. Studies on risk through earthquake recurrence interval suggests that the region is susceptible to damaging earthquakes of magnitude 6.0 and more with the recurrence interval of 2 to 10 years. The recurrence intervals for the earthquakes of magnitude 8.0 / 6.0 for this region, using Gumbel's and G.R. extreme values theory (Table 6.4) works out as 102 / 11 years (Srivastava & Dattatrayam, 1986).

Table 6.4 - Predicted Earthquake Recurrence Intervals in Indo-Western Nepal Border Region

Earthquake Magnitude	Gumbel's Method		G. R. Method 1905 – 1977
	1905 – 1976	**1962 – 1976**	
5.0	2.72	3.09	4.63
5.0	5.15	8.32	8.03
6.0	10.37	24.38	13.94
6.5	21.48	73.54	24.20
7.0	45.14	223.87	42.00
7.5	95.49	683.64	72.90
8.0	102.63	2089.84	126.53
8.5	430.62	-	219.61

G.R. - Gutenberg – Ritcher's Relationship Method

The neighbourhood of studied landslides at Mangti on the Indo – Nepal border records high seismicity and is seismically the most active region in the Central Himalayas, showing distribution of epicenters adjacent to major thrusts and faults. Valdiya (1986) has postulated this high seismicity, largely attributed to the strike-slip movement along the tear faults. The intensity distribution map of 1979, 1980 earthquakes (Kumar et. al. 1981) shows concentration parallel to the Munsiari Thrust-MCT and the Chiplakot strike slip fault falls in adjoining Goriganga Valley. Although, there is no documented records correlating earthquakes vis–a–vis landslide events from the study area, however, role of seismicity as triggering factor cannot be ruled out.

There have been considerable attempts to correlate earthquakes as triggering factor in causing landslides. Correlations made by Keefer (1984) between magnitude (M) and landslide distribution suggests maximum area likely to be affected by landslides in a seismic event increases from approximately zero at M = 4.0 to 500,000 km^2 at M = 9.2. Important factors that govern relative levels of shaking that trigger landslides are – Threshold magnitudes, minimum shaking intensities and relations between M and distance from epicenter or fault rupture (Keefer, 1984). Each type of earthquake – induced landslide occurs in a particular suite of geologic environments, ranging from overhanging slopes of well indurated rocks to sub-horizontal slopes underlain by soft, unconsolidated sediments.

Further, materials most susceptible to earthquake – induced landslides include weakly cemented rocks, more – indurated rocks with prominent discontinuities, residual and colluvial sands, cemented soils and alluvium.

To relate seismic parameters to landslide distribution following measures (Keefer, 1984) have been suggested –

1. The smallest earthquakes that cause landslides,
2. Relation between magnitude and area affected by landslides,
3. Relation between magnitude and maximum distance of landslides from the fault rupture, and
4. Minimum shaking intensity at which landslides are triggered.

The debatable issue is whether small magnitude earthquakes can cause landslide or not; as landslides can also be triggered by non-seismic causes like rainfall event or it can be initiated even by weak shaking. Information pertaining to scale of magnitude and probable landslide types is given in Table 6.5.

Table 6.5 - Scale of Earthquake Magnitude and Landslide Types

Earthquake Magnitude (M_L)	Landslide Types
4.0	Rock falls, Rockslides, Soil falls and disrupted Soil Slides
4.5	Soil Slumps, Rock Block Slides
5.0	Rock Slumps, Rock Block Slides, Slow Earth Flows, rapid Soil Flows and sub-aqueous landslides
6.0	Rock Avalanches
6.5	Soil Avalanches

(After Youd and Perkins, 1978)

So far assessment on earthquake – induced landslides in the study area is concerned, lack of information on any specific landslides triggered during a known earthquake event made it difficult to bring out any definite conclusion. However, an attempt has been made using study areas' earthquake events as gathered from Indian Meteorological department and U. S. Geological Survey and correlating with any recorded landslide incidence. As there exists number of epicenter locations in the near proximity of Mangti Landslide ± 50 km radius (Figure 6.4) and important regional thrusts / tear faults etc.; large number of landslide incidences fits well with specific earthquake event (Table 6.6). But, majority of landslide incidences are confined to monsoon period, therefore, it would not be wrong to ascribe both earthquake ($M > 3$) and rainfall event > 22 mm/day as triggering factor to cause landslides. Seismicity factor has been incorporated as one of the vital aspects for deriving an overall EIA of the area under Landslide Hazard Zonation studies.

Table 6.6 - Observed Earthquake Events vis-à-vis Landslide Incidence and Rainfall

Date & Year	Epicenter Distance from Landslide (km)	Magnitude	Number of Landslide Incidences Recorded within a Week Period	Rainfall (mm)
17.06.2001	-	2.50	01	32.50
11.07.2001	30	3.00	07	33.75
14.07.2001	-	2.80	02	22.75
25.07.2001	77	3.80	09	40.00
04.06.2002*	93* - 27†	5.6 – 3.7 14 Earthquake Tremors	01	NR
05.06.2002†				NR
06.06.2002				NR
09.06.2002				28.00
12.06.2002				14.50
08.07.2002	-	3.20	04	NR
05.08.2002	-	3.80	15	14.50
09.08.2002	33	3.70		31.25
14.08.2002	33	3.80		03.00
09.09.2002	80	3.10	03	11.25
04.07.2003	-	3.0	04	08.50
15.07.2003	-	3.0	12	09.00
28.08.2003	45	3.9	02	29.50
03.09.2003* ***(05 Events)**	71	4.8 Max.		15.75* **
5^{th}, 8^{th}, 12^{th} and 23^{rd} September	33	< 3	39	27.50, 10.25, 43.75 & 17.50 mm.
03.04.2004	39	4.60	01	NR
17.04.2004	43	4.10	01	NR
15.06.2004	46	4.20	01	NR
09.09.2004	48	4.4	03	13.97
17.09.2004	-	4.5	06	NR

**Area has recorded on an average 27 mm/day rain in previous week

Note: *Between July – August 2004 although no EARTHQUAKE EVENT RECORDED but area has accounted for more than 80 landslide incidences attributed to periodic recurrence of rainfall event, i.e., > 22 mm/day.*

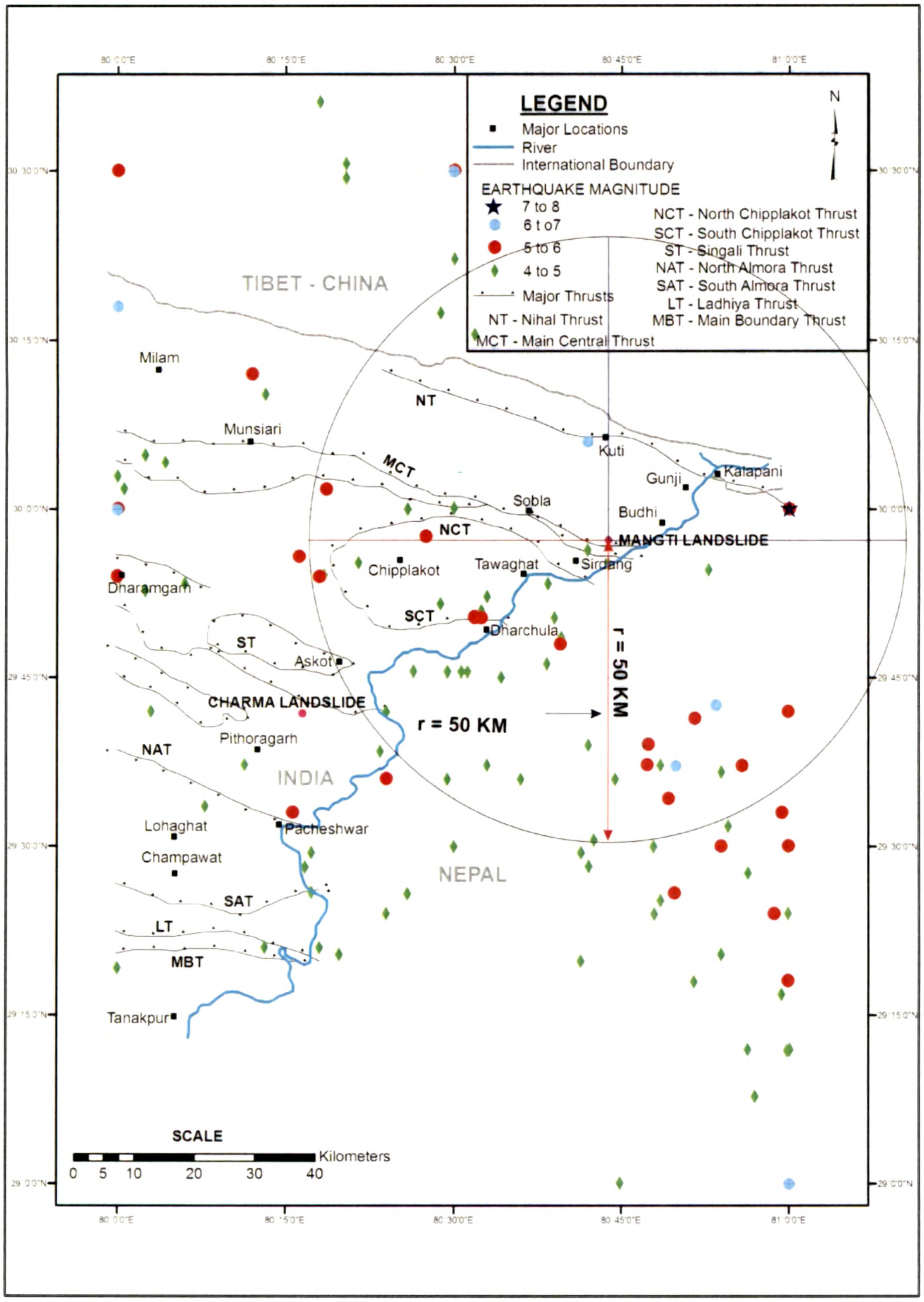


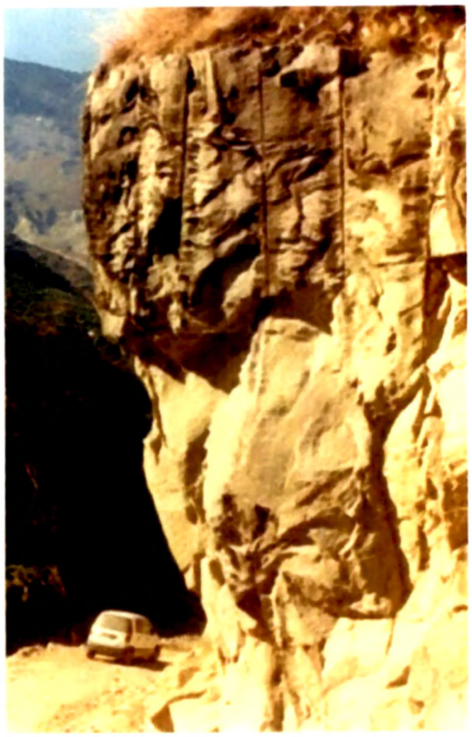
Figure 6.4 - Seismo-tectonic Map of the Kali River Corridor

ANTHROPOGENIC FACTORS

The constructed strategic road along the Tawaghat – Jipti Route Corridor is very severely affected by the landslide hazards. During every monsoon season, which is also the period of Kailash – Mansarovar yatra the landslides are causing great inconvenience to the pilgrims due to road blockades.

In-depth studies of discontinuities carried out by the candidate through an elaborate Scanline survey and historical landslides record has revealed that the very inception of majority of landslides are attributed to the road development.

For want of progress and to accomplish the given time targets the road building agencies had to carry out extensive un-controlled blasting. Due to closely spaced blast holes and use of high power detonators, the released energy apart from giving fast results, has developed large number of closely spaced and irregular joints/fractures/cracks and have also widened the existing joint systems in the rocks. During field investigations large numbers of such radiating and irregular joint/fracture patterns that normally weaken the rock masses and allow water to percolate inside to further reduce the rock strength were observed. The ensuing pictorial presentation (Plate VI.2 A-F) amply proves this fact.

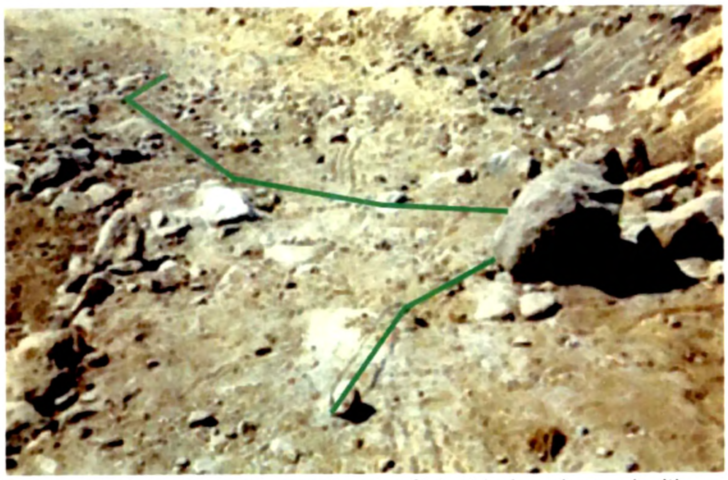


A. View of closely spaced blast holes along TJRC

B. View of fixing explosives in blast holes along the road further ahead of Galagad village towards Jipti

C. Fieldphotograph of completely filled balst hole with explosives, connected in network with a detonator

Plate VI.2 – contd....



D. Layout plan of a random network of blast holes charged with explosives during construction phase of last 1km stretch of TJRC beyond Galagad village towards Jipti

E. Field photograph of the fractured rock mass after carrying out uncontrolled blasting during construction phase of last 1km stretch of TJRC beyond Galagad village towards Jipti

F. Field photograph of radiating fractures created in Biotite Gneiss rock in shoulder region of Mangti Landsllide on account of uncontrolled blasting carried out during road construction stage

Plate VI.2 - Pictorial Depiction of Uncontrolled Blasting Generated Fracture Pattern along TJRC