

# LANDSLIDES

## **I. What is a Landslide?**

The term 'landslide' includes all varieties of mass movements of hill slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another. Although the landslides are primarily associated with mountainous terrains, these can also occur in areas where an activity such as surface excavations for highways, buildings and open pit mines takes place.

Landslide is a general term for a wide variety of downslope movements of earth materials that result in the perceptible downward and outward movement of soil, rock, and vegetation under the influence of gravity. The materials may move by falling, toppling, sliding, spreading, or flowing. Some landslides are rapid, occurring in seconds, whereas others may take hours, weeks, or even longer to develop.

## **II. What are Mudflows?**

Mudflows (or debris flows) are fluid mass of rock, earth, and other debris saturated with water. Mudflows are characteristics of steep, scanty vegetated slopes on which heavy rainfall initiates movement in a thick layer of weathered material. They develop when water rapidly accumulates in the ground, such as during heavy rainfall or rapid snowmelt, changing the earth into a flowing river of mud or slurry. Slurry can flow rapidly down slopes or through channels, and can strike with little or no warning at avalanche speeds. A slurry can travel several miles from its source, growing in size as it picks up trees, cars, and other materials along the way.

## **III. Causes of Landslides**

Many factors contribute to slides, including geology, gravity, weather, groundwater, wave action, and human actions. Although landslides usually occur on steep slopes, they also can occur in areas of low relief. Landslides can occur as ground failure of river bluffs, cut and-fill failures that may accompany highway and building excavations, collapse of mine-waste piles, and slope failures associated with quarries and open-pit mines. Underwater landslides usually involve areas of low relief and small slope gradients in lakes and reservoirs or in offshore marine settings. Typically, a landslide occurs when several of these factors converge.

### **I. Natural Factors**

(i) **Gravity:** Gravity works more effectively on steeper slopes, but more gradual slopes may also be vulnerable.

(ii) **Geological factors:** Many slides occur in a geologic setting that places permeable sands and gravels above impermeable layers of silt and clay, or bedrock. Water seeps downward through the upper materials and accumulates on the top of the underlying units, forming a zone of weakness.

**(iii) Heavy and prolonged rainfall:** Water is commonly the primary factor triggering a landslide. Slides often occur following intense rainfall, when storm water runoff saturates soils on steep slopes or when infiltration causes a rapid rise in groundwater levels. Groundwater may rise as a result of heavy rains or a prolonged wet spell. As water tables rise, some slopes become unstable.

**(iv) Earthquakes:** Seismic activities have always been a main cause of landslides throughout the world. Any time plate tectonics move the soil that covers moves with it. When earthquakes occur on areas with steep slopes, many times the soil slips causing landslides. Furthermore, ash debris flows caused by earthquakes can also trigger mass movement of soil.

**(v) Forest fire:** fires cause soil erosion and induce floods and landslides due to the destruction of the natural vegetation. (eg. ridges of Manipur-Nagaland border).

**(vi) Volcanoes:** Strato volcanoes are prone to sudden collapse, especially during wet conditions. (E.g. May 18, 1980, magma moved high into the cone of Mount St. Helens and shoved the volcano's north side outward by at least 150 m. Within minutes of a magnitude 5.1 earthquake at 8:32 a.m., a huge landslide completely removed the bulge, the summit, and inner core of Mount St. Helens, and triggered a series of massive explosions.)

The conditions commonly prevail after volcanic eruptions that kill vegetation over extensive areas and spread loose volcanic rocks over the landscape. During subsequent rainy seasons, swollen rivers will erode the new deposits and sometimes generate lahars that are dangerous to people downstream. (E.g. lahars at Mount Pinatubo, Philippines in 1990)

**(vii) Waves:** Wave action can erode the beach or the toe of a bluff, cutting into the slope, and setting the stage for future slides.

## **II. Anthropogenic Factors**

Human actions most notably those that affect drainage or groundwater, can trigger landslides eg are Inappropriate drainage system, change in slope/land use pattern, deforestation, agricultural practices on steep slopes, cutting & deep excavations on slopes for buildings, roads, canals & mining ,inappropriate disposal of debris after excavations are examples.

### **(i) Inappropriate drainage system:**

Natural drainage lines on slopes are blocked by terracing/ contour bounding adopted to prevent soil erosion and to enhance percolation during dry season for cultivation, without adequate provision for surface drainage of excess storm water during high intensity rains increase the landslide vulnerability.

**(ii) Cutting & deep excavations on slopes for buildings, roads, canals & mining:** Developmental activities like construction of buildings, road cutting, embankments, cut and fill structures causes modification of natural slopes, blocking of surface drainage, loading of critical slopes and withdrawal to toe support promoting vulnerability of critical slopes.

(iii) **Change in slope/land use pattern, deforestation, agricultural practices on steep slopes:** Deforestation and cultivation of seasonal crops and increase in settlements. Improper land use practices such as heavy tilling, agricultural practices and settlement patterns have contributed to creep and withdrawal of toe support in many cases

#### IV. Types of Landslides

The common types of landslides are described below. These definitions are based mainly on the work of Varnes (Varnes, D.J., 1978)

- (i) **Falls:** Abrupt movements of materials that become detached from steep slopes or cliffs, moving by free-fall, bouncing, and rolling.
- (ii) **Flows:** General term including many types of mass movement, such as creep, debris flow, debris avalanche, lahar, and mudflow.
- (iii) **Creep:** Slow, steady downslope movement of soil or rock, often indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences.
- (iv) **Debris flow:** Rapid mass movement in which loose soils, rocks, and organic matter combine with entrained air and water to form slurry that then flows downslope, usually associated with steep gullies.
- (v) **Debris avalanche:** A variety of very rapid to extremely rapid debris flow.
- (vi) **Lahar:** Mudflow or debris flow that originates on the slope of a volcano, usually triggered by heavy rainfall eroding volcanic deposits, sudden melting of snow and ice due to heat from volcanic vents, or the breakout of water from glaciers, crater lakes, or lakes dammed by volcanic eruptions
- (vii) **Mudflow** Rapidly flowing mass of wet material that contains at least 50 percent sand-, silt-, and clay-sized particles.
- (viii) **Lateral spreads** Often occur on very gentle slopes and result in nearly horizontal movement of earth materials. Lateral spreads usually are caused by liquefaction, where saturated sediments (usually sands and silts) are transformed from a solid into a liquefied state, usually triggered by an earthquake.
- (ix) **Slides** Many types of mass movement are included in the general term "landslide." The two major types of landslides are rotational slides and translational landslides.
  - (a) **Rotational landslide** The surface of rupture is curved concavely upward (spoon shaped), and the slide movement is more or less rotational. A slump is an example of a small rotational landslide.
  - (b) **Translational landslide** The mass of soil and rock moves out or down and outward with little rotational movement or backward tilting. Translational landslide material may range from loose, unconsolidated soils to extensive slabs of rock and may progress over great distances under certain conditions.
  - (c) **Topple** A block of rock that tilts or rotates forward and falls, bounces, or rolls down the slope.

## Common landslide types

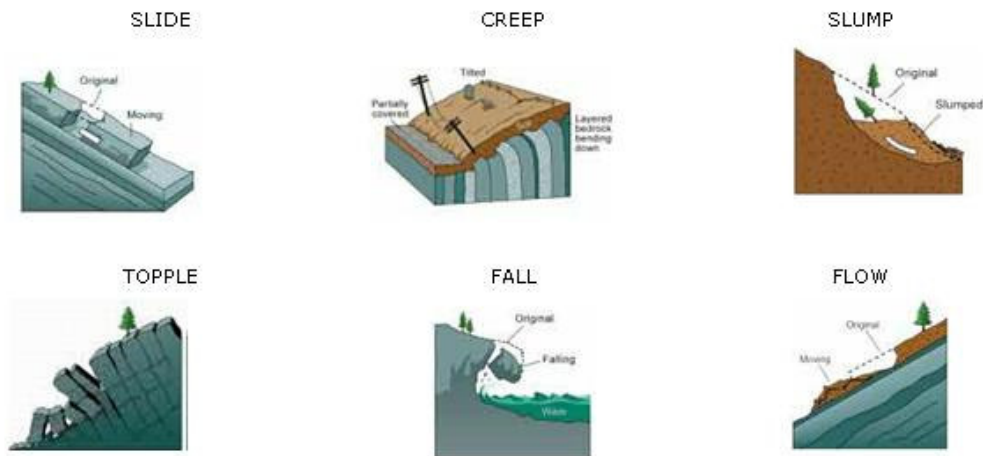


Figure 1

## V. Where does Landslides mostly occur?

### Where they have occurred before.

Large, deep-seated slides tend to be a reactivation of existing landslide complexes. Slope stability maps can provide an excellent indication of unstable areas. A competent geological analysis can usually provide an estimate of stability of problem areas on a site. It cannot reliably provide a probability of failure or an exact map of the area to be affected.

### On steep slopes

Steep slopes are typically found along shorelines where centuries of wave or river currents have eroded the toe of the slope. Most steep slopes experience sliding.

### On benches

Relatively level benches on an otherwise steep slope often indicate areas of past slope movement.

### Where drainage is causing a problem

Landslides are often triggered by the failure of drainage systems. Large amounts of water flowing from driveways, roof areas, roads and other impermeable surfaces can cause slides.

### Where certain geologic conditions exist

Landslides occur where certain combinations of soils are present. When layers of sand and gravel lie above less permeable silt and clay layers, groundwater can accumulate and zones of weakness can develop.

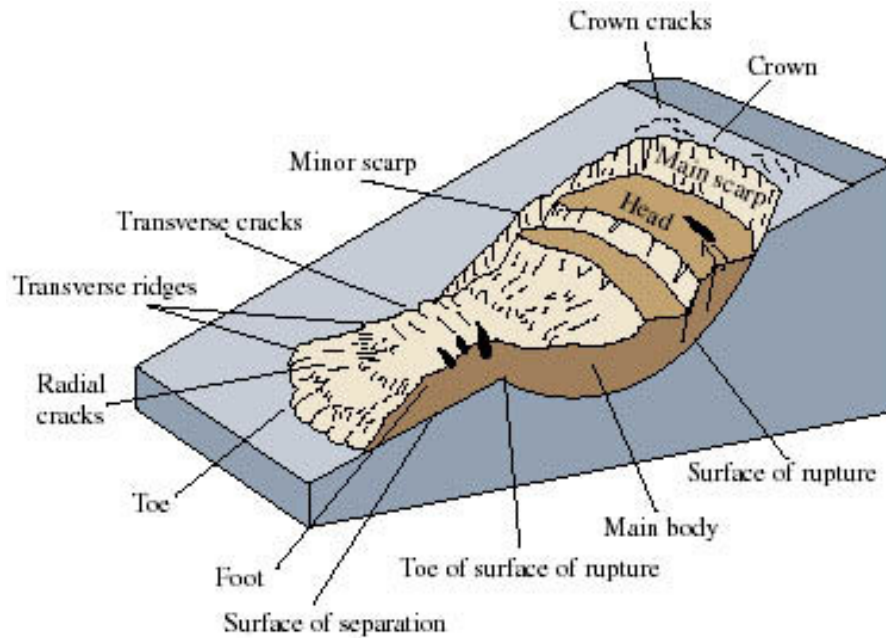


Figure 2

## VI. How do landslides affect us?

In hilly terrains of India, Himalayan mountains, western ghats and northeastern part, landslides have been a major natural disasters that strike life and property almost perennially. These landslides, year after year, bring about untold misery to human settlements apart from causing devastating damages to transportation and communication network.

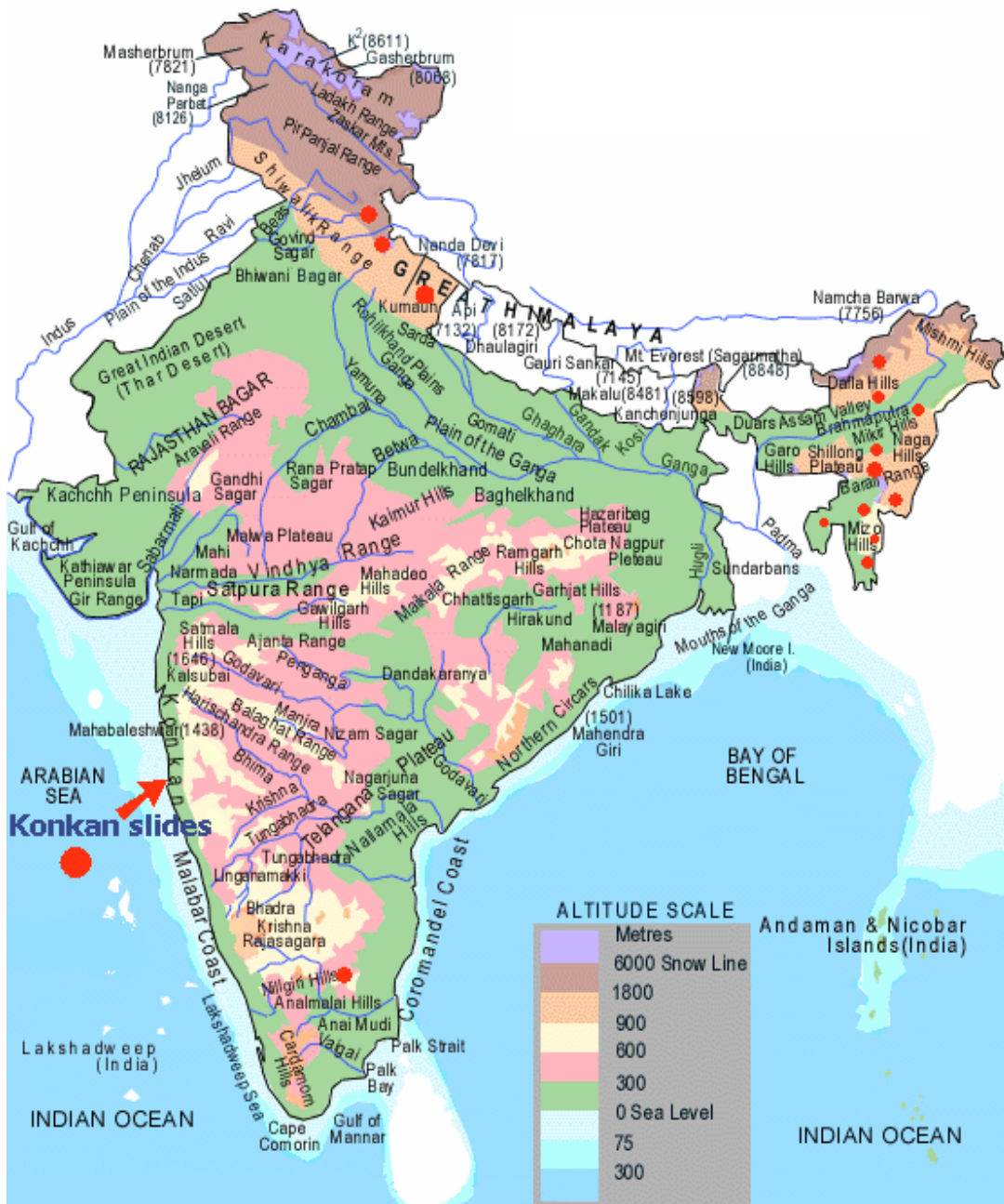
**Landslides cause property damage**, injury and death and adversely affect a variety of resources. For example, water supplies, fisheries, sewage disposal systems, forests, dams and roadways can be affected for years after a slide event.

**The negative economic effects of landslides** include the cost to repair structures, loss of property value, disruption of transportation routes, medical costs in the event of injury, and indirect costs such as lost timber and lost fish stocks.

Water availability, **quantity and quality** can be affected by landslides. Geotechnical studies and engineering projects to assess and stabilize potentially dangerous sites can be costly. Large, infrequent landslides contribute less to personal and property losses than do the smaller, more frequent slides and debris torrents in populated areas.

Every year in India especially in mountain regions like Himalaya landslides damage many houses and cause millions of rupees damage to buildings, roads, railways, pipelines, agricultural land and crops.

## VII. Indian Profile:



**Figure 2** Landslide Prone Areas

Source : IITB, <http://www.csre.iitb.ac.in/rn/resume/landslide/india.htm>

# **Landslide Disasters - India**

## **Major Landslides**

### **1. Thangi Slide**

The Thangi slide is located at km 389.2 on H.T. road (NH-22) on the right bank of Sutluj river opposite the confluence with Tirung Khad. The rocks here are highly jointed, low dipping mica schist of lower Haimanta Group. The schists are interbanded with quartzite layers. Numerous apophyses and veins of granite and pegmatite occur along joints and foliation.

It is a recurring landslide disrupting the traffic and transport on national highway after heavy snowfall and its melting. It is a composite slide-cum-wedge failed rockfall in the part and debris slide in the lower part. The thickness of the soil and weathered mantle along the road cut is 0.5 m and upto 1 to 3.5 . respectively. The chemical weathering evidenced by white and yellow encrustation has made the rocks very weak and friable. The lower and middle slopes are covered with old glacial debris. the upslope area is covered with open forest and middle slopes are occupied by fields and orchards. The lower slopes are barren rock cliffs.

The barren and steep lower slope had become unstable due to toe erosion by Satluj river and also due to cutting in the road widening. High density of joints and fractures and the contact between unconsolidated and morainic debris and parent rocks have created channels for water seepage which has moistened the slopes and in turn reduced shear strength of the slope material. In the initial stages, a rockfall had occurred in the upper part of this slide along two wedge fractures dipping  $80^\circ$  towards SE  $72^\circ$  towards SW direction. Falling of boulders from rockfall on the debris cone coupled with undercutting of already moistened slope by the Satluj river had reactivated the debris cone lying below the rockfall on the steep slope to slide along slip plane dipping  $56^\circ$  towards downslope. The high discharge of Tirung Khad has forced the Satluj river towards west to undercut the slope.

### **Khadra Dhang**

Khadra Dhang slide zone (75 x 1300 x 10m), was activated in the early sixties and is still active. It is located on the old Hindustan - Tibet road along the right bank of river Satluj, opposite to Ribba. The valley slopes here are mainly covered with semiconsolidated old glacial debris resting on weathered granitic gneisses. The slide is a translational debris slide which occurred in lower and middle slopes. The upper slopes are covered with open forest and middle slopes by agricultural land. Though slope material is generally dry but seepage zones and springs present in the lower stretches glacial debris, this build up the pore water pressure and thus reducing the shear resistance of the material. The sparsely vegetated semiconsolidated old glacial debris had become dangerously unstable following the initiation of road cuttings. The seepage had converted the glacial debris into slurry and excavation of the semiconsolidated unstable slope for road construction have disturbed the critical shear stress equilibrium.

This coupled with over steepening of the already steep slope ( $48^\circ$  dipping SSW) due to toe cutting by river Satluj have contributed to translational debris slide along a slip plane dipping  $70^\circ$  towards SSW. Though the H.T. road has now been diverted to the left bank of the river, but toe cutting by river Satluj during peak discharge continuously causes active sliding.

### **Pangi Slide**

Pangi slide (measuring  $65 \times 300 \times 6$  m) is located on Pangi Kalpa link road its junction with NH-22 (371.25 km stone). It occurred in biotite gneiss and garnetiferous mica schist of Vaikrita Group covered with old scree and boulders of gneisses. The slide is located in embankment part of the lower valley slopes, dipping  $48^\circ$  NW, along Pangi Nala.

The slide is a rotational debris slide in the upper part and translational planner slide in the lower part along the alip plane dipping  $70^\circ$  towards SW which is parallel to the dipping  $60^\circ$ ,  $70^\circ$  and  $55^\circ$  towards NNE, SE, SSW respectively, have converted the rock mass into blocks. Freezing and thawing action in the joints has further reduced the cohesive strength of the rocks. A number of cracks have also developed along the flank of the slide during road construction. The presence of seasonal seepages within the sear indicate building up of pore-water pressure and toe cutting by the Pangi Nala have rendered the slopes unstable. This together with uncontrolled blasting for the construction of NH - 22 - Kalpa link road has also contributed to the generation of this slide.

### **Powari Landslide**

The Powari landslide zone (measuring  $1000 \times 500 \times 25$  m), is one of the largest landslides located on the lower slope along the right bank of Satluj river between Powari and Peo in a terrain composed by highly jointed weathered and fractured, mica gneisses of Vaikrita formation.

The 1962 survey of India map shows the existence of a small landslide. The major slide occurred about 15 years ago after the construction of approach road from Powari to Kalpa. This road climbs through six hair pin bends and three stretches have been affected badly by the slides.

The landslide is a composite slide which represents a combination of debris fall along upper part, rotational slump in middle slope and debris slide at the toe. At least four landslides scars are visible. The first scar formed due to debris fall, is a small one present below fifth bend of road and the second one is a wedge rockfall along joints dipping  $70^\circ$  towards SE. The third scar is formed due to planner debris slide along foliation plane and the fourth scar is formed due to debris slide and slumps. A number of slumps scars and seepages are present on each bend. The dip of the failure plane and slip surface varies between  $61^\circ$  and  $70^\circ$  and dipping towards SSE and SE direction. Foliation planes (dipping  $34^\circ$  and NE) of gneiss and 3 set of prominent joints and fractures dipping in the slope direction. The saturated overburden consisting of old glacial debris, rich in mica, are responsible for the slope failure. An irrigation canal passing along the upper part of the

slope is contributing water to a number of seepage zones located within the slumped mass. This together with snow melt has resulted in the build up of pore water pressure over a long period of time and gradual decrease in shear resistance and have also pulverized overlying micaceous rich old glacial debris and slope material. This together with road, excavation of slopes for the hair pin bend (five loops in slope length of 500m) road construction from Powari to Peo and continuous toe erosion by Satluj river has triggered the slide. The presence of NE-SW oriented transverse cracks (4-5 m scar length) on the flank of fourth scar, convex slope in toe portion, tilted trees, continuous debris slide sinking of road due to active slumping are indicative of continued downward movements or creep within the slumped mass. The U shape road bends in a stretch of 500m slope length. Continuous seepage of water at the H.T. Road and along road to Peo at different levels indicates that the water from irrigation canals needs to be diverted from controlling the slide. The road has subsided by 3-4 meters along lower three bends.

### **Barua Slide**

The Barua landslide (measuring 60 x 100 x 15 m) is located on the left middle slope in the Bapsa valley about 5km southeast of Karcham. Though, the slide was triggered in 1987-88 it has been repeatedly activated. The thickness of the soil - mantle along the road cut is of the order of 1.5-2m. The location of the landslide is close to the Karcham and Vaikrita thrusts. The sparsely vegetated steep lower valley slope dipping 73° towards west 10° south, zig-zag road and moderate upslope (25° towards WSW) covered with old glacial material has become unstable following the widening the road. Seasonal snow melt from upper slope in old glacial material has build up pore water pressure and thus reduced the shear strength. The removal of toe to widen the road and already moistened glacial material and seasonal seepage from upslope has contributed to the occurrence of this landslide along the sliding plane dipping 58° due WSW. The road to village Shong from Karcham has subsided by 5-7m and is not in use any more. A number of houses as well as orchards and fields have also been damaged.

### **Urni Rockfall**

The Urni rockfall (500 x 250 x 5 m ) is located near village Tapri along the lower slope, on the right bank of river Satluj on Hindustan-Tibet road (NH-22) (347.00km) in highly jointed Wangtu gneisses. While the upper slopes are covered with old glacial debris and open forest, the lower slope are barren. The thickness of soil and weathered mantle along the road cut is 0.5 to 0.8m. Though no seepage or springs are visible in the slide zone, seasonal seepage from snow melt does take through the joints.

Over steepening of slopes due to toe cutting by the Satluj river has been further intensified by rockfall on the opposite bank, forcing the river towards present slide. This over together with opening of joints due to uncontrolled blasting for the widening of NH-22 have reduced the shear strength of the rock mass and led to rockfall along wedge joints. The fallen rock block range from 7-8m across. Five person died due to reactivation of this slide in 1992.

### **Nachar Slide**

The Nachar landslide (350 x 200 x 35 m) in the lower middle slope on left bank of Satluj river is located on NH-22 road in highly jointed and sheared granite-gneiss of central Crystallines (Jutogh Groups). The gneisses have interbanded amphibolites and are cut across by a network of the pegmatic veins. Numerous shear zones (1-2m thick), parallel to the foliation planes are traversing the host rock. The thickness of the soil and weathered mantle along the road cut is of the order 50-70 cm. The upper slope (40° due North) is covered with old rockfall and glacial deposits resting on dip slopes and joints dipping 54° towards NNE. Village Nachar and Paunda are situated on these slopes. The upper is occupied by fields and orchard. The lower slopes are moderately dipping at 43° towards north. There is one seepage zone present in the slide zone and one seasonal stream on the other flank of the slide. Five sets of closely spaced fractures and joints developed due to tectonic activity and uncontrolled blasting have broken the rock into blocks and act as easy passages for water seepage. The seepage through these joints and fracture and upper slope debris over a long period of time has reduced the shear strength of the rock. The toe cutting by the Satluj river and widening of the NH-22 road had over steepened the slopes. Thus adverse rock dip and slope relationship and seepage of water from upper slopes have caused this complex rockfall and debris slide.

### **Soldan Khad Slide**

The slide measuring (200 x 200 x 15 m) is located along the right bank of the Soldan Khad, a tributary of Satluj river. The lower valley slope dipping 33° towards NW in a terrain composed of highly sheared and crushed rocks of Wangtu gneissic complex. The slopes are covered with old glacial and landslide debris. A flash flood occurred in Sep. 1988 following heavy rains due to a cloud burst, brought down about 6-105 m debris within 24 hours and caused heavy loss of human and cattle lives, property and orchard fields. In Soldan valley the thickness of soil mantle and weathered rocks is of the order of 1.5-6 m. The upper slope area is covered with old glacial and landslide debris on which agricultural and horticultural lands of village Salpa, Soldan and Paunda are located.

The landslide is a combination of rotational debris slump in the upper part and translational slide in middle and lower part. Schistosity plane of weathered gneisses dipping 35° towards N60° W almost parallel to slope are responsible for the slope failure. Excess seepage from the agricultural field located in upper slope area had increased the pore water pressure over a long period resulted in the decrease in shear resistance and excess overland flow due to cloud burst have triggered this slide. The toe cutting by the Soldan Khad have also over-steepened the slope and also contributed in sliding. The monsoonal rains of Sep. 1992 have further deteriorated the situation and resulted in debris flow.

### **Jakhri Slide**

The Jakhri landslide (500 x 500 x 15 m) on the left valley slopes of the Sutluj valley is located on NH-22 (288/450 km stone) in highly weathered and sheared mica gneisses of

Jutogh/Wangtu Gneiss Complex covered with fluvio-glacial and colluvial debris .The thickness of soil and weathered mantle along the road cut is of the order of 2.0 to 10 m. The upper slope area is covered with agricultural fields of Shah and Ghaso villages are situated. The location of the landslide is in the vicinity of main central thrust and east-west trending Nogli Gad Fault. The sparsely vegetated lower valley slope (dipping 28° NNE) is dangerously unstable following the construction of link roach for Jakhri Hydel project sitr which has reactivated the old landslide debris.The first slide occurred in JULY, 1992 following monsoonal rainfall.

The greater slide occurred on 24 Feb,1993 following heavy winter rains. The slipped mass (37.5 x 105m ) temporarily blocked the river Satluj and within 48 hours a lake was formed which was 1.5 km long, 25-30m deep and 15-20m.The lake in reduced dimension remains in existence for 7-8 months.

This landslide is a translational debris slide. Foliation/schisosity planes of micaceous gneiss dipping 18° towards N 15° E, parallel to the slope are responsible for the slope failure.The shearing of the rocks is related to the main central thrust. Continued seepages from the agricultural field,seasonal rainfall and snow melt into already wet old debris and rocks over a long period of time resulted in decrease inshear resistance.This together with toe cutting by the Satluj river and unfavorable rock dipping gentler (20° NNE) in the slope direction contributed to the occurence of this slide, along the sliding plane dipping 18° towards N 15° E.The presence of 1-2 m wide transverse cracks on both flank of the landslide and in the crown portion are indicative of continued downward movement within the slide.

## VI. HISTORY

### Major Catastrophic Landslides of the 20<sup>th</sup> Century

Country names are for today's countries.

Year	Country (State/Province)	Name & type(s)	Triggering process	Vol. of material (m <sup>3</sup> except where noted)	Impact	Comments
1911	Tadzhik Rep. (Formerly USSR)	Usoy rock slide	Usoy earthquake M = 7.4	2.0 x 10 <sup>9</sup>	Destroyed Usoy village; 54 killed; dammed Murgab River, impounding 65-km long still existing Lake Sarez	Casualties low because of sparse population
1919	Indonesia (Java)	Kalut lahars (Volcanic mudflows)	Eruption of Kalut volcano	185 km <sup>2</sup>	5,110 killed; 104 villages destroyed or damaged	Draining of Crater Lake caused hot

						mud flows
1920	China (Ningxia)	Haiyuan landslides	Haiyuan earthquake	???	100,000 killed; many villages destroyed	675 large loess landslides created more than 40 lakes
1921	Kazakh Rep. (formerly USSR)	Alma-Ata debris flow	Snowmelt	???	500 killed	Debris flow in Valley of Alma-Atinka River
1933	China (Sichuan)	Deixi landslides	Deixi earthquake M = 7.5	>150 x 10 <sup>6</sup>	6,800 killed by landslides; 2,500 drowned when landslide dam failed	Earthquake caused several major landslides; largest formed 255-m-high dam on Min River
1939	Japan (Hyogo)	Mount Rokko slides and mud flows	Heavy rain	???	505 dead/missing; 130,000 homes destroyed or badly damaged by mass movements and/or floods	Caused by major typhoon; 50-90% of impact of Japanese typhoons caused by mass movements
1949	Tadzhik Rep. (formerly USSR)	Khait rock slide	Khait earthquake M = 7.5	???	12,000 - 20,000 killed or missing; 33 villages destroyed	Began as rock slide; transformed into large loess and granite debris avalanche
1953	Japan (Wakayama)	Arita River slides and debris/mud flows	Heavy rain	???	460 dead/missing; 4,772 homes destroyed by mass movements/floods	Caused by major typhoon; 50-90% of impact of Japanese typhoons caused by mass movements
1953	Japan (Kyoto)	Minamiy-amashiro slides & debris/mud flows	Heavy rain	???	336 dead/missing; 5,122 homes destroyed or	"

					badly damaged by mass movements/floods	
1958	Japan (Shizuoka)	Kanogawa slides and mud/debris flows	Heavy rain	???	1,094 dead/missing; 19,754 homes destroyed or badly damaged by mass movements/floods	"
1962	Peru (Ancash)	Nevados Huascaran debris avalanche	???	$13 \times 10^6$	4,000-5,000 killed; much of village of Ranrahirca destroyed	Major debris avalanche from Nevados Huascaran; average velocity 170 km/hour
1963	Italy (Friuli-venezia-Griulia)	Vaiont Reservoir Rockslide	???	$250 \times 10^6$	2,000 killed; city of Longarone badly damaged; total damages: US\$200 million (1963 \$)	High-velocity rock slide into Vaiont Reservoir caused 100-m waves to overtop Vaiont Dam
1964	United States (Alaska)	1964 Alaska landslides	Prince William Sound Earthquake M = 9.4	???	Estimated US\$280 million (1964 \$) damages	Major landslide damage in cities of Anchorage, Valdez, Whittier, Seward
1965	China (Yunnan)	Rock slide	???	$450 \times 10^6$	Four villages; 444 dead	Occurred at "high speed"
1966	Brazil (Rio de Janeiro)	Rio de Janeiro slides, avalanches, debris/mud flows	Heavy rain	???	1,000 dead from landslides and floods	Many landslides in Rio de Janeiro and environs
1967	Brazil (Serra das Araras)	Serra das Araras slides, avalanches, debris/mud flows	Heavy rain	???	1,700 dead from landslides and floods	Many landslides in mountains SW of Rio de Janeiro
1970	Peru (Ancash)	Nevados Huascaran debris avalanche	Earthquake M = 7.7	$30-50 \times 10^6$	18,000 dead; town of Yungay destroyed;	Debris avalanche from same

					Ranrahirca partially destroyed	peak as in 1962; attained average velocity of 280 km/hr.
1974	Peru (Huancavelica)	Mayunmarca rock slide-debris avalanche	Rainfall? River erosion?	$1.6 \times 10^9$	Mayunmarca village destroyed, 450 killed; failure of 150-m-high landslide dam caused major downstream flooding	Debris avalanche with average velocity of 140 km/hr. dammed Mantaro River
1980	United States (Washington)	Mount St. Helens rock slide-debris avalanche	Eruption of Mount St. Helens	$2.8 \times 10^9$	World's largest historic landslide; only 5-10 killed, but major destruction of homes, highways, etc.; major debris flow; deaths low because of evacuation	Evacuation saved lives; began as rock slide; deteriorated into 23-km-long debris avalanche with average velocity of 125 km/hr.; surface remobilized into 95-km-long debris flow
1983	United States (Utah)	Thistle debris slide	Snowmelt & heavy rain	$21 \times 10^6$	Destroyed major railroad and highways; dammed Spanish Fork flooding town of Thistle; no deaths	Total losses: US\$600 million (1983 \$)—50% direct losses, 50% indirect losses
1983	China (Gansu)	Saleshan landslide	???	$35 \times 10^6$	237 dead; buried four villages; filled two reservoirs	Loess landslide
1985	Colombia (Tolima)	Nevado del Ruiz debris flows	Eruption of Nevado del Ruiz	???	Four towns and villages destroyed; flow in valley of Lagunillas River killed more than 20,000 in city of Armero.	Death toll unnecessarily large because hazard warnings not passed to residents

1986	Papua, New Guinea (East New Britain)	Bairaman Rock slide-debris avalanche	Bairaman earthquake M = 7.1	200 x 10 <sup>6</sup>	Village of Bairaman destroyed by debris flow from breached landslide dam; evacuation prevented casualties; huge effect on local landscape	Debris avalanche formed 210-m-high dam that impounded 50-million m <sup>3</sup> lake; dam failed, causing 100m-deep debris flow-flood downstream.
1987	Ecuador (Napó)	Reventador landslides	Reventador earthquakes M = 6.1 and 6.9	75-110 x 10 <sup>6</sup>	1,000 killed; many kms of trans-Ecuadorian oil pipeline and highway destroyed; total losses: US\$ 1 billion (1987 \$)	Land sliding mainly in saturated, residual soils on steep slopes; thousands of thin slides remobilized into debris flows in tributary and main drainages.
1994	Colombia (Cauca)	Paez landslides	Paez earthquake, M = 6.4	250 km <sup>2</sup>	Several villages partially destroyed by landslides; 271 dead; 1,700 missing; 158 injured; 12,000 displaced.	Thousands of thin, residual-soil slides on steep slopes turned into damaging debris flows in tributary and main drainages.
1998	Honduras, Guatemala, Nicaragua, El Salvador	Hurricane Mitch <ul style="list-style-type: none"> <li>• flooding</li> <li>• Landslides</li> <li>• debris-flows</li> </ul>	Hurricane Mitch		Approximately 10,000 people killed in the flooding and landslides, which occurred throughout the region. Casitas volcano in Nicaragua experienced large	180-mile per hour winds affected Honduras primarily. Torrential rains occurred, at the rate of 4 inches per hour. Large

					debris flows. Impossible to differentiate deaths from landslides from deaths due to flooding.	landslides in Tegucigalpa and elsewhere.
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*Source: USGS*

*(<http://landslides.usgs.gov/learningeducation/majorls>)*

**Table 1 : Some of the major Landslides in India ( 1990-2005)**

October 1990	Nilgris	36 people killed and several injured. Several buildings and communication network damaged
July 1991	Assam	300 people killed, road and buildings damaged, Millions of rupees
November 1992	Nilgris	Road network and buildings damaged, Rs.5 million damage estimate
June 1993	Aizawal	4 persons were buried
July 1993	Itanagar	25 people buried alive 2 km road damaged
August 1993	Kalimpong, West Bengal	40 people killed, heavy loss of property
August 1993	Kohima, Nagaland	200 houses destroyed, 500 people died, about 5km road stretch was damaged
November 1993	Nilgris	40 people killed, property worth several lakhs damaged
January 1994	Kashmir	National Highway 1A severely damaged
June 1994	Varundh ghat, Konkan Coast	20 people killed, breaching of ghat road damaged to the extent of 1km. At several places
May 1995	Aizwal Mizoram	25 people killed road severely damaged
June 1995	Malori Jammu	6 persons killed, NH 1A damaged
September 1995	Kullu, HP	22 persons killed and several injured about 1 km road destroyed
14, August 1998	Okhimath	69 people killed
18, August 1998	Malpa, Kali river	205 people killed road network to Mansarovar disrupted
August 2003	Uttarkashi	Heavy loss of infrastructures
July 2004	Joshimath - Badrinath	Heavy landslides hit Lambagarh areawashed away nearly 300 meter long road between Joshimath and Badrinath, 17 killed
August 03, 2004	Landslide at Tehri dam project;	9 killed

## **Structural and Non Structural Mitigation Measures**

### **Drainage Corrections:**

The most important triggering mechanism for mass movements is the water infiltrating into the overburden during heavy rains and consequent increase in pore pressure within the overburden. Hence the natural way of preventing this situation is by reducing infiltration and allowing excess water to move down without hindrance. As such, the first and foremost mitigation measure is drainage correction. This involves maintenance of natural drainage channels both micro and macro in vulnerable slopes.

**Proper land use measures:** Adopt effective land-use regulations and building codes based on scientific research. Through land-use planning, discourage new construction or development in identified hazard areas without first implementing appropriate remedial measures.

### **Structural measures:**

Adopt remedial techniques (i.e., buttresses, shear keys, sub-drains, soil reinforcement, retaining walls, etc.) of existing landslides that are in close proximity to public structures (Rogers, 1992 for examples).

**Afforestation:** The afforestation programme should be properly planned so the little slope modification is done in the process. Bounding of any sort using boulders etc. has to be avoided. The selection of suitable plant species should be such that can with stand the existing stress conditions of the terrain.

**Awareness generation:** Educate the public about signs that a landslide is imminent so that personal safety measures may be taken.

Some of these signs include:

- (i) Springs, seeps, or saturated ground in areas that have not typically been wet before.
- (ii) New cracks or unusual bulges in the ground, street pavements or sidewalks.
- (iii) Soil moving away from foundations, and ancillary structures such as decks and patios tilting and/or moving relative to the house.
- (iv) Sticking doors and windows, and visible open spaces.
- (v) Broken water lines and other underground utilities.
- (vi) Leaning telephone poles, trees, retaining walls or fences.
- (vii) Sunken or dropped-down road beds.
- (viii) Rapid increase in a stream or creek water levels, possibly accompanied by increased turbidity (soil content).
- (ix) Sudden decrease in creek water levels even though rain is still falling or just recently stopped.

**Financial Mechanisms:** Support the establishment of landslide insurance

**Legal and Policy:** legislation to direct a governmental or private program to reduce landslide losses should be strengthened.

### **Preparedness for Mitigating Landslide Hazard:**

#### **(i) Before the Landslide:**

**Develop a Family Disaster Plan.** Develop landslide-specific planning.

Learn about landslide risk in your area. Contact local officials or departments of natural resources, and university departments of geology. Landslides occur where they have before, and in identifiable hazard locations. Ask for information on landslides in your area, specific information on areas vulnerable to landslides, and request a professional referral for a very detailed site analysis of your property, and corrective measures you can take, if necessary.

If you are at risk from landslides:

- (a) Develop an evacuation plan. You should know where to go if you have to leave. Trying to make plans at the last minute can be upsetting and create confusion.
- (b) Discuss landslides and debris flow with your family. Everyone should know what to do in case all family members are not together. Discussing disaster ahead of time helps reduce fear and lets everyone know how to respond during a landslide or debris flow.

#### **(ii) During a Landslide**

- (a) Stay alert and awake. Many debris-flow fatalities occur when people are sleeping. Listen to early warning of intense rainfall. Be aware that intense, short bursts of rain may be particularly dangerous, especially after longer periods of heavy rainfall and damp weather.
- (b) If you are in areas susceptible to landslides and debris flows, consider leaving if it is safe to do so. Remember that driving during an intense storm can be hazardous. If you remain at home, move to a second story if possible. Staying out of the path of a landslide or debris flow saves lives.
- (c) Listen for any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing or falling mud or debris may precede larger landslides. Moving debris can flow quickly and sometimes without warning.
- (d) If you are near a stream or channel, be alert for any sudden increase or decrease in water flow and for a change from clear to muddy water. Such changes may indicate landslide activity upstream, so be prepared to move quickly. Don't delay! Save yourself, not your belongings.
- (e) Especially alert when driving. Embankments along roadsides are particularly susceptible to landslides. Watch the road for collapsed pavement, mud, fallen rocks, and other indications of possible debris flows.

#### **(iii) After the Landslide**

Stay away from the slide area. There may be danger of additional slides

- (i) Check for injured and trapped persons near the slide, without entering the direct slide area. Direct rescuers to their locations.
- (ii) Help a neighbour who may require special assistance - infants, elderly people, and people with disabilities. Elderly people and people with disabilities may require additional assistance. People who care for them or who have large families may need additional assistance in emergency situations.
- (iii) Listen to local radio or television stations for the latest emergency information.
- (iv) Watch for flooding, which may occur after a landslide or debris flow. Floods sometimes follow landslides and debris flows because they may both be started by the same event.
- (v) Look for and report broken utility lines to appropriate authorities. Reporting potential hazards will get the utilities turned off as quickly as possible, preventing further hazard and injury.
- (vi) Check the building foundation, chimney, and surrounding land for damage. Damage to foundations, chimneys, or surrounding land may help you assess the safety of the area.
- (vii) Replant damaged ground as soon as possible since erosion caused by loss of ground cover can lead to flash flooding.
- (viii) Seek the advice of a geotechnical expert for evaluating landslide hazards or designing corrective techniques to reduce landslide risk. A professional will be able to advise you of the best ways to prevent or reduce landslide risk, without creating further hazard.

### **National Initiatives**

National Core Group for Landslide Mitigation was constituted by Ministry of Home Affairs. First meeting of the core group was held on 5<sup>th</sup> October , 2004 under the chairman ship of Secretary Boarder Management, MHA. In order to prevent and mitigate the landslide risk, the National Core Group have decided the following.

- (i) **Finalisation of uniform methodologies** for Landslide Hazard Zonation on Macro and meso scales: GSI has applied the provisions of these BIS codes for landslides hazard Zonation and prepared a draft suggesting the revision of BIS codes.
- (ii) **Developing Methodologies for Landslide Hazard Zonation on Meso Scales:** The existing BIS code does not prescribe the methodologies for landslide zonation on meso scales. It has been decided that BIS will come up with provisions for landslide hazard zonation on meso scales.
- (ii) **Landslide Hazard Zonation of the Vulnerable Areas on Macro Scale:** It has been estimated that about 10,000 kms route is to be covered on Macro Scale to have quick preliminary appraisal of large areas, identified critical slopes and prioritise areas for detailed studies. It has been decided that GSI

will identify the routes in consultation with the State Governments. The National Remote Sensing Agency will provide remote sensing data and Survey of India will provide the topographical maps on required scales to GSI. It has been decided to constitute a Technical Committee comprising NRSA, SOI and DST with GSI as convener to review the work of landslide hazard zonation of vulnerable areas on macro scales in a time bound manner.

- (iii) **Landslide Hazard Zonation of the Vulnerable Areas on Macro Scale:** Site specific survey to be done on a higher scale i.e., 1: 10,000 or 1:5,000 scales in the inhabited areas or the sites proposed for infrastructure development.
- (iv) **Developing Landslide Risk Mitigation Plan:** After the completion of hazard zonation on macro and meso scales, GSI in consultation with members of technical committee will develop specific set of guidelines for landslide risk mitigation for various zones in the country to be followed by all Central and State Government Ministries/ Departments and Agencies.
- (v) **Monitoring of Recurring Landslides:** There are many sites which are active and pose danger to communication routes or cause river blockages and these sites to be monitored continuously. It is estimated that there are 30 such sites where mapping on a scale of 1:500 – 1:200 is required to be initialized for mitigation planning.
- (vi) **Rapid response** to suggest immediate measures in the event of Landslides: there are about 30 incidences of Landslides which occur near habitation or along the communication routes which require immediate appraisal and mitigation advise. GSI with its field network would attend these incidents. GSI will upgrade its communication links and link their control rooms with MHA and State Control Rooms for reporting incidences.
- (vii) **Early Warning Systems:** There is a need to evolve an early warning system for landslides. Some work has been done in this regard by CSIO, Chandigarh. For the prediction model for landslides early warning system to be effective, a landslide incidence inventory will be developed by GSI in consultation with the state governments and other agencies such as BRO, CPWD etc. For the entire frame work of the early warning system to be developed and implemented, it has been decided to constitute a Technical Committee comprising of IIT Roorkee, IIT Kharagpur, SCIO, CBRI, NIRM, THDC, IMD, CWC, NRRRNWF and DST. GSI will be the convener of this Committee and periodically report will be submitted to MHA on progress.
- (viii) **Awareness generation:** It has been decided that GSI will develop awareness generation strategy in consultation with the Ministry of Home Affairs and take up awareness programmes in the hazard prone areas to raise awareness at various levels through media campaigns, development and distribution of leaflet posters, meetings, workshops on a priority basis. GSI will also hold discussions with All India Radio, Doordarshan and other channels of television for spreading awareness in landslide
- (ix) **Coordination:** GSI has been declared as the nodal agency for landslides by Govt. of India vide Ministry of Coal and Mines communication No. 11 (5) 04-M. I dated 29<sup>th</sup> January 2004. It has been decided that landslide zonation is carried out only with approval from GSI so as to avoid duplication of work.

And ensure that landslide hazard zonation is carried out in line with the prescribed parameters.

- (x) **Reporting:** Periodical reports on the progress in the implementation of the action plan to be submitted to MHA for discussion and review by the National Core Group for Landslide Mitigation .

### **Future Plans**

### **Settlement policy**

Drawing upon the Kerala study in parts of Western Ghats (referred to earlier), it has been felt that while permanent settlement should be avoided in high-risk zones, site selection even in moderately safe zones, especially in plateau edge regions should be made with caution. Diversion of stream channels in upper slopes, especially above settlement should strictly disallow. Adequate provision should made to ensure drainage of storm water away from the high sloping terrain so as to reduce over saturation, Any contour bounding, or terracing adopted for seasonal cultivation or initiation of plantations in slopes of >160 above settlement should have sufficient provision for storm water drainage. Further, in such areas the existing natural drainage channels and hallows are to be meticulously maintained without any attempt at blocking, division or modification.

### **Connected Links**

1. Landslides Information System developed by Centre of Studies in Resources Engineering (CSRE) <http://www.csre.iitb.ac.in/rn/resume/landslide/lsi.htm>
2. The NLIC publishes in various venues such as USGS fact sheets, books, pamphlets, and posters, and will provide personnel to present landslide information in schools, civic organizations, and other interested governmental entities. <http://landslides.usgs.gov/nlic/>
3. International Landslide Research Group, **ILRG is an informal group of individuals concerned about sharing information on landslide research and promoting regional landslide analyses.** <http://ilrg.gndci.cnr.it/>
4. The Federal Emergency Management Agency (FEMA) provides "fact sheets" - including preparedness tips - concerning most natural and technological hazards. A fact sheet on landslides is available at <http://www.fema.gov/hazards/landslides/landslif.shtm>
5. The Washington State Department of Ecology recently launched this excellent site on landslides in the Puget Sound region. It includes information about landslides generally, warning signs, what to do if you have a slide, what to do to prevent slides, and where and how to obtain help. It also lists frequently asked questions (FAQs) and provides slope maps and a slide show on causes, recent occurrences, repair, and prevention of landslides. Much of the information on the site could be useful to people in other regions. <http://www.colorado.edu/hazards/resources/landslides.html>
6. Geological Survey of India, <http://www.gsi.gov.in>
7. Centre for earth Science Studies. <http://www.cessind.org/thrustareasnew.htm>

## **References**

1. Landslide hazard Zonation Atlas of India, Building Materials Technology Promotion Council & Centre for Disaster Mitigation and management, Anna University.
2. Action Plan for Landslide Risk Mitigation, Ministry of Home Affairs , Office Memorandum, November 3, 2004.
3. Textbook of Physical Geology - Mahapatra G. B.

## **Research Past and Current**

## **Resources and documents**

## **Annexure/ Photos**