3.Why landslides are a growing hazard

There are many and often complex causes of landslides, acting over time scales of minutes to millennia. Landslides are often associated with regions experiencing intense geological uplift, weathering and water-related erosion. The occurrence of a landslide is usually a direct response to one or more 'trigger factors' or external events that cause the slope to fail. Rainfall and earthquakes are the most common.

Throughout Asia, intense and/or prolonged storms and rainfall frequently trigger landslides while landslides also occur in drier regions as a result of earthquakes. Heavy rainfall, together with earthquakes, compounds the problem, such that even small tremors can initiate landslides. It is likely that changes in climate or weather will exacerbate many of these problems.

Other longer-term changes can also affect slope stability.[39] Frequently, changes in land use that involve soil excavation or loss of forest cover make slopes susceptible to failure. As human development has extended into hilly and mountainous areas in Asia, landslide incidence has risen above the natural 'background' level. For example, 80 percent of landslides in China result from human activities, with dam-building and road construction being the most significant causes.[192]

Activities most often associated with increases in landslide frequency include road and rail construction, hill-side construction, water pooling, agriculture and livestock rearing, logging and surface mining. The activities themselves rarely initiate a landslide without the occurrence of other contributory factors, such as high rainfall or earthquakes. However, the activities are critical because they lower the thresholds for landsliding.

3.1 Changing rainfall and snowmelt patterns

Large volumes of water entering the soil can destabilize hillslopes such that a large storm or cyclone can initiate hundreds of landslides. The scale of the impact and the potential for disaster is greatly

increased by contributory factors such as land use and proximity to settlements or infrastructure.

Intense storms are a primary cause of landslides, but events of much lower intensity can trigger landslides if forest removal has increased susceptibility to water saturation. Without reduction of soil moisture through forest transpiration, a period of rainfall causes soils to become saturated more rapidly and additional rainfall or seismic activity can trigger slides. This is particularly likely at the end of the rainy season when high soil moisture content and water pressures create instability. In monsoonal areas, exceptional pre-monsoon rains may also produce this effect at the beginning of the rainy season.

Similar effects may occur during snowmelt when rising temperatures cause rapid melting or rain-on-snow events to release excessive amounts of water. Consequently, the seasonality and pattern of rainfall and snowmelt, in addition to storm intensity and duration, are critical determinants of sliding.

3.2 Earthquakes and seismic activity

The impacts of earthquake-induced landslides are escalating because of rising population densities and economic development in areas once thought too remote or too steep for development. Widespread landsliding due to earthquakes is restricted to rare large earthquakes. Earthquakes smaller than magnitude 6.0 contribute negligible amounts to total landslide volumes.[113] However, a single large earthquake can initiate thousands of landslides in an area up to 250 kilometres or more from the epicentre,[180] although the vast majority occur on or near the fault-line.[207] Additionally, slopes that do not fail may become predisposed to landsliding in the event of another tremor or moderate rainfall.[114]

In some areas, such as western New Guinea and to a lesser extent in Turkey, central Japan, the Islamic Republic of Iran and Tibet Autonomous Region of China, earthquake-induced landslides are the main agents of slope erosion.[113] They occur periodically in many other countries but in humid areas their importance is below that of rainfall-induced landslides. In dry climates, earthquake-induced landslides are relatively more frequent, and occur especially when soil moisture content is high.[214]

It is important to note that landslides triggered by earthquakes are typically deep-seated and frequently cause failures along planes of weakness within the bedrock in which the forces involved are so large that the presence of forests has little or no effect on most slope failures.

Figure 3.1. Deep seated landslide resulting from the 2008 Sichuan earthquake. Trees had no mitigating effect
Courtesy: Patrick Durst.

3.3 Road and railway construction

Roads and railways are important contributors to increased landslide incidence.[187, 109] Road and railway construction frequently involves cutting slopes and removing soil from hillsides. Trees are invariably removed even when there is no soil excavation. Removal of soil and trees results in a significant reduction in lateral support to soil and landsliding often occurs subsequently. Roads built across mid-slopes and at the base of hills constitute the highest landslide risk due to subsurface water interception, undercutting and creation of additional load on slopes.[182]

Ideally, railways and major roads are designed to higher standards than smaller trails and logging roads and there are frequently requirements for engineering works to stabilize affected slopes and minimize landslide hazard. Nonetheless, rapidly constructed roads often do not reach required standards of engineering.[192]

Trails and tracks associated with agricultural development and afforestation programmes, although associated with much less soil excavation, are also a significant cause of landslides.[13,202] Concentrated storm flows associated with trails and tracks often lead to gully erosion and landsliding.[202] Landslides can occur where water discharges onto slopes from the track or trail, or from culverts associated with larger roads. Landslides can also result where gullies are created due to accelerated rates of infiltration.[161]

Figure 3.2. Landslide following road construction in Bhutan
Courtesy: Patrick Durst.

3.4 Deforestation and land-use conversion

Many activities associated with economic development – agriculture, logging, mining, residential development, tourism, etc. – bring land-use and land-cover change and loss of forests.[1] The loss of roots and the reinforcement they provide may significantly increase the likelihood of slope failure.[176,15,112]

Removal of forest or brush cover and replacement with grass or crops has often been found to substantially increase the susceptibility of hillslopes to landsliding (Box 4).[162,79,147,13,100,1] Although the replacement land-use type determines relative slope stability, most land uses are inferior to forests. Unlike weathering, groundwater content, rainfall or earthquakes, however, deforestation can be addressed and potentially controlled on relatively short time scales.

In Asia, deforestation is primarily driven by rising demand for agricultural land, both for subsistence farming and, increasingly, for commercial and industrial agriculture. Forest degradation also results from the expansion of logging – legal and otherwise – and shifting cultivation, which may end in conversion of forest to some other land use. Migration into forested areas and their subsequent development is facilitated in particular by the opening of roads – often to support logging or plantation development.

BOX 4 - Tree removal and the window of landslide susceptibility

The removal of trees and shrubs from hill slopes makes slopes susceptible to landslides. Loss of protective function persists until woody vegetation is re-established and sufficient stem and root density is achieved. The 'window of susceptibility' commences when roots begin to die and decay. Within three to five years small roots may lose over half their original tensile strength and significant increases in landslides can be expected after this.[142,141]

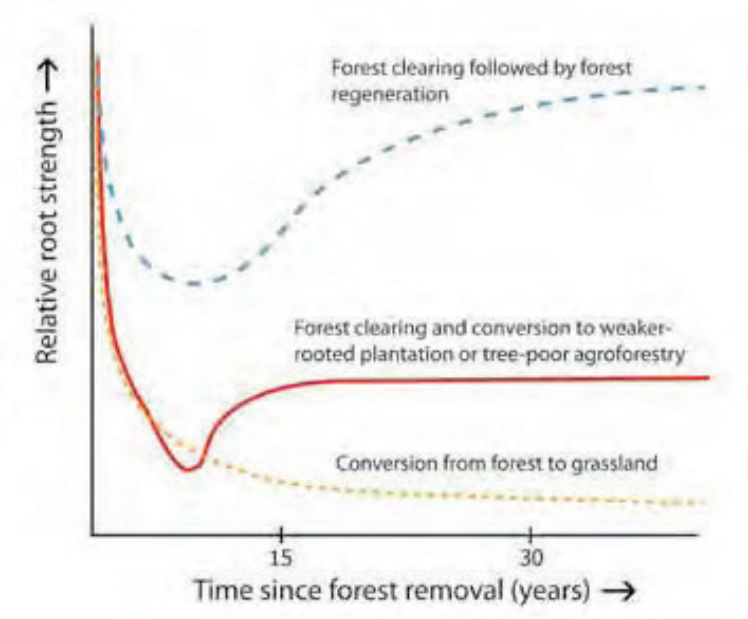

Figure 3.3. Forest clearing and the window of susceptibility

Where forested slopes are converted to cropland, pasture or other land uses, the effect will be permanent and even in newly established coffee, tea and timber plantations, landslides are still likely to be common. Where vegetation removal occurs cyclically, such as in logging or shifting cultivation, the window of susceptibility is open until roots re-establish.[118, 11] Where logging takes place, susceptibility is substantially reduced if selective silvicultural systems are employed instead of clear-cutting.[206]

The window of susceptibility (corresponding to the dip in Figure 3.3) may remain open for 15 to 20 years;[221,115,220] less in the humid tropics where regeneration is quicker (five to seven years)[211,118] and longer at high altitudes in temperate regions where it is slower.[4] Because shifting cultivation will temporally arrest natural succession and deplete soil nutrients, regeneration will be delayed and the window of susceptibility may become longer.