4.Implications of climate change

The close association between landslides, rainfall and other climatic variables make future changes in climate particularly important in determining the significance of landslides.

Climate change factors relevant to landslide incidence are:

1) Changes in annual and seasonal precipitation;
2) Increased mean air temperature; and
3) Increased frequency and intensity of extreme events (severe storms, cyclones/typhoons, droughts).

With excessive amounts of rain, thresholds of slope stability are quickly surpassed and landslides may be triggered. Rising temperature causes more extreme storms, speeds up soil and bedrock weathering, and elevates risk of wildfires that denude slopes and further hasten weathering.[34] On the other hand, higher summer temperatures accelerate transpiration rates and reduce soil moisture content, thereby reducing landslide risk providing drought does not damage vegetation and weaken root reinforcement.

Climate anomalies and changes in the frequency of extreme climatic events in Asia over past decades, although not necessarily evidence of climate change, have included increased occurrence of extreme rains causing, for example, flash floods in Viet Nam; landslides and floods in the Philippines in 1990 and 2004; and floods in Cambodia in 2000.[40] Generally, the frequency of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides and debris/mud flows.[40] Other changes in past decades have included:

- In western and southern China, the frequency of extreme rains has been increasing in the last decade. An increase in the intensity of summer rains in eastern China has also been recorded;
- In Japan, extreme rains have become more frequent over the past 100 years and an increase in maximum rainfall has also been recorded;

- In South Asia, Bangladesh, Nepal and northeast India in particular, increases in extreme rainfall events have been reported and increases in the intensity of cyclones in the Bay of Bengal have been recorded in recent years;
- More frequent typhoons in the Philippines and stronger as well as more frequent typhoons in China have been recorded.
- Rapid thawing of permafrost and decrease in depths of frozen soils due to rising temperature have caused more frequent landslides and degeneration of some forest ecosystems in China and Mongolia.[40]

Looking to the future, precipitation is expected to increase over most of Asia in the period to 2039, particularly during the northern hemisphere winter. Most regional climate change studies project changes in the seasonal distribution of rainfall, with drier and/or longer dry seasons and shorter, more intense wet seasons.[106] In South Asia, increased rainfall during the northern summer is expected, while in Southeast Asia little change is foreseen until 2040.[40]

In combination with changes in precipitation, temperature increases are also expected across the region and an increase in occurrence of extreme weather including heat waves and precipitation events is predicted in South Asia, East Asia and Southeast Asia. In association, increases in tropical cyclone intensities by 10-20 percent are expected in Asia, while temperature is projected to increase by 0.7-1.8°C in South, Southeast and East Asia and 1.5-2.9°C in the Tibetan Plateau and North Asia.[40] In Japan, significant increases in both temperature and precipitation are predicted.

The predicted increases in extreme rainfall events are likely to increase the frequency of landslides in sloping areas, while cyclonic winds may induce landslides by toppling trees, exposing bare soil and increasing saturation failures.[169] Warmer weather and longer dry seasons are at the same time expected to affect tree physiology, forest growth and biodiversity while raising the incidence of fire, forest die-back and spread of pests, pathogens and invasive species.[186, 40]

Increased road development and rising levels of human activity in forest areas are also likely to increase the incidence of fire.[171] Root decay resulting from tree death by fire or disease is in turn likely to affect slope stability and fire is also likely to directly reduce soil stability and permeability.[179] Maintenance of forest health and vitality will therefore become increasingly important in slope protection as well as other climate change-related goals.[45,177]

All subregions of Asia are expected to see a significant acceleration of warming over that observed in the past century.[183] The predicted changes in temperature and precipitation will not, however, be uniform across Asia. Similarly the intensity of storms, cyclones and precipitation will rise in some areas and decline in others.

Based on the IPCC Fourth Assessment Report[102] the following predictions are made for seven subregions of Asia. Discussion focuses on the near-term period, 2010-2039.[195]

4.1 North Asia

The northern parts of China and Mongolia will probably experience the greatest increases in temperature and precipitation relative to other parts of Asia. Temperatures are expected to be up to 2.7-2.9°C higher in the winter and 1.7-2.2°C higher the rest of the year. Significant melting of permafrost over vast territories,[107] and perhaps completely in the southern fringe of North Asia,[145] will result in extensive rock falls and slides, debris flows, thermal erosion as permafrost weakens, ground surface subsidence and impoundment of water. A greater frequency of extreme summers is likely to lead to significant increases in seasonal thaw depths.[96] Winter and spring precipitation is expected to increase between 10 and 16 percent and rise between 4 and 7 percent in summer and autumn. Increased snow and likelihood of rain-on-snow events during warmer springs will increase landslide incidence.

Predictions for summer are less clear. Although rainfall will be higher, temperatures and transpiration will also rise so the net effect on soils is difficult to predict. Predictions of fire hazard are, for the same reason, unclear. Nevertheless, one study suggests that for an average temperature increase of 1°C, the duration of the wildfire season in North Asia could increase by 30 percent.[204] Also, warmer winter temperatures will reduce winter insect kill and lead to explosions in insect populations that can kill forests over vast areas. Aside from loss of soil reinforcement, once roots begin to decay, standing dead trees are highly susceptible to wildfire.

4.2 Tibetan Plateau

The Tibetan Plateau will also experience similar impacts of permafrost loss and increased landslide incidence. Year-round temperatures may increase 1.5-2.1°C and cause progressive shrinkage of the permafrost area.[212] Glaciers are also melting at very high rates. Combined with significantly greater snow and rain (10-14 percent in winter and 4-7 percent during the rest of the year) landslide and debris flow incidence can be expected to increase, particularly during the spring-melt period and the Plateau's monsoon starting in May.

4.3 East Asia

China, Japan, Republic of Korea and DPRK are likely to experience moderately high year-round temperature increases (1.3-1.8°C). Winter precipitation may be 5-6 percent higher and spring/summer rainfall may rise 2-3 percent (change in autumn rainfall is negligible). While these changes are not severe, many parts of East Asia are already very susceptible to landslides, due to high rainfall and unstable soils, and small changes could drastically increase landslide hazard. For example, areas of loess – accounting for some 6.6 percent of the land area of China – are highly erodible and can disintegrate instantaneously when saturated, if vegetation is absent.[44] Japan has many areas with fragile geology that is easily weathered and susceptible to sliding, volcanic soils in particular.[34] East Asia is also subjected to typhoons of increasing frequency and intensity.[56] During these extreme events, landslides will be numerous and widespread, particularly in coastal areas.

4.4 South Asia

In India, southern Pakistan, Nepal, Bhutan, Bangladesh, Myanmar and Sri Lanka, moderately high precipitation increases can be expected with temperature increases of 1°C or less. Increases in pre-monsoon rains (7-8 percent) and monsoon rains (5-7 percent) could lead to a significant rise in landslide incidence in the Himalayas, Sri Lankan highlands and Western Ghats of India. Furthermore, the period of elevated landslide risk will lengthen because increased pre-monsoon rain in April and May will cause soil moisture to build up sooner. In Sri Lanka and southern India, landslide incidence is greatest during the retreating monsoon, between October and December. At this time, the expected increase in rainfall is only 1-3 percent. But in Kerala, like Nepal and Bhutan, where most annual precipitation falls during the monsoon, a small amount of additional rainfall, particularly at the end of the season, may lead to significant numbers of landslides if soils are near saturation. Additionally, the severity of South Asian tropical cyclones and storms is increasing although their frequency appears to be declining.[119]

4.5 Southeast Asia

The countries of Southeast Asia will experience the smallest increases in temperature (0.7-0.9°C) and negligible changes in precipitation. However, because hot, humid conditions are conducive to high rates of biological and chemical weathering of bedrock, slight changes in precipitation and temperature may still significantly alter landslide frequency. On the other hand, in relatively drier parts

of the subregion higher temperatures will cause soils to dry, thus reducing landslide incidence. Nevertheless, both humid and drier areas will be susceptible to the predicted increase in frequency and intensity of typhoons and convection storms. The combined effects of flooding, debris flows and high winds could potentially lead to catastrophic events in densely populated coastal areas.