

20. Engineering geological issues of the Nepal Himalaya

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Abstract

Geologically young and tectonically active Himalayan Range is characterized by highly elevated mountains and deep river valleys. The mountainous terrains of Nepal Himalaya are characterized by highly dynamic physical processes, and therefore, implementation of infrastructure development projects is a big challenge. Similarly, more pragmatic approaches of construction and maintenance of infrastructure are needed in Nepal comparing with other mountain terrains of the world. A better understanding of the geological nature of the terrain and the interaction of various triggering factors of natural hazards will greatly help in the development of safer infrastructures, mitigation of natural hazards, and control of land degradation in the Himalaya. Many constructed and running projects have faced various problems during survey, design and construction phases; during the process of project construction and maintenance, invaluable experience has been gained during the last five decades. Over the last fifty years, Nepal has gained a remarkable amount of experience in the low cost process of landslide studies and stabilization; survey, design and construction of roads; hydropower tunnels and dams; hazard and risk assessment in the community level, low-cost rural road engineering; slope protection by bioengineering etc. Thus, this paper provides an overview of present conditions of engineering geology in Nepal Himalaya and their impact on infrastructure development.

1 INTRODUCTION

The Himalayan Range is one of the youngest mountain systems on the world. It is a broad continuous arc along the northern fringes of the Indian subcontinent, from the bend of the Indus River in the north-northwest to the Brahmaputra River in the east-southeast. The Himalayan mountain chain measures 2400 km in length and remains one of the most active and fragile mountain ranges on the earth. Being a Himalayan county and owing to the rugged topography, complex geological settings, soft soil cover, high intensity rainfall during monsoon periods, and frequently occurring earthquakes, the natural phenomena such as landslides, debris flows, soil erosion, and other mass wasting processes are some of the common forms of natural disaster in Nepal. The combination of the weak rock and thick soil cover and monsoon climate makes each physiographic zone of Nepal very hazardous. Mass movement in the Nepal is scale-dependent, from the massive extension of whole mountain ranges (gravity tectonics), through the failure of single peaks, to the smallest slope failures. In these contexts, for development of safer infrastructures, mitigation of natural hazards and environmental degradation in the Himalaya, a better understanding of geological nature of terrain and interplay of prime triggering factor with soil and rock is indispensable.

2 PHYSIOGRAPHY AND GEOLOGY OF NEPAL

The Himalaya forms a sharp geographic boundary between the high Tibetan plateau of east-central Asia in the north and the subdued south Asian subcontinent in the south. This narrow and highly rugged major mountain range of Asia was formed by the latest mountain building activity in the Earth's history. The Himalaya was formed by the collision of the northward moving Indian plate with the giant Asian landmass. This convergence builds up the force to push the Himalaya upward as well as horizontally, thereby making it the most restless mountain range in the world. The orogenic process is continuous from the collision of Indian plate with the giant Asian landmass and the mountain is still on making process. This is noticeable by present day northward movement of India at the rate of 15 mm to 50 mm per year and the occurrences of frequent seismic shakes all along the Himalaya and its surroundings (Bilham et al., 1998). Most part of the drift is accommodated within the Himalaya by various thrusts as well as rising peaks.

Nepal is located in the central part of the Himalayan arc and occupies nearly one third of the mountain range. Physiographically, 83% of Nepal falls within the mountainous terrain and the remaining 17% lies in the northern edge of the alluvial plains of the great Gangetic Basin. Nepal is well defined into eight physiographic provinces from south to north, namely; (1) Terai (the northern edge of the Indo-Gangetic plain), (2) Siwalik (Churia) Range, (3) Dun Valleys, (4) Mahabharat Range, (5) Midlands, (6) Fore Himalaya, (7) Higher Himalaya, and (8) Trans Himalaya. Each of these units has unique altitudinal variation, slope, relief characteristics, and climatic pattern. The physiographic maps of Nepal with major mountain peaks are given in Fig 1. Geologically, Nepal can be divided into five tectonic zones from north to south: the Tibetan-Tethys Himalayan Zone, Higher Himalayan Zone, Lesser Himalayan Zone, Siwalik Zone, and Terai Zone (Fig 2). The main structural framework of the Himalaya is formed by three northerly inclined major breaks in the upper crust of the Indian Plate namely, the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT). Each of geological zones

is characterized by their own lithology, tectonics, structures and geological history. These all tectonic zones are separated from each other by the thrust faults. The southernmost fault, the Main Frontal Thrust (MFT) separates the Sub-Himalayan (Siwalik) Zone from Gangetic Plains. The Main Boundary Thrust (MBT) separates the Lesser Himalayan Zone from Siwalik. The Main Central Thrust (MCT) separates the Higher Himalayan Zone from the Lesser Himalayan Zone. The South Tibetan Detachment System (STDS) marks the boundary between the Higher Himalayan Zone and the overlying sedimentary sequence of the Tibetan-Tethys Himalayan Zone (Fig 2).

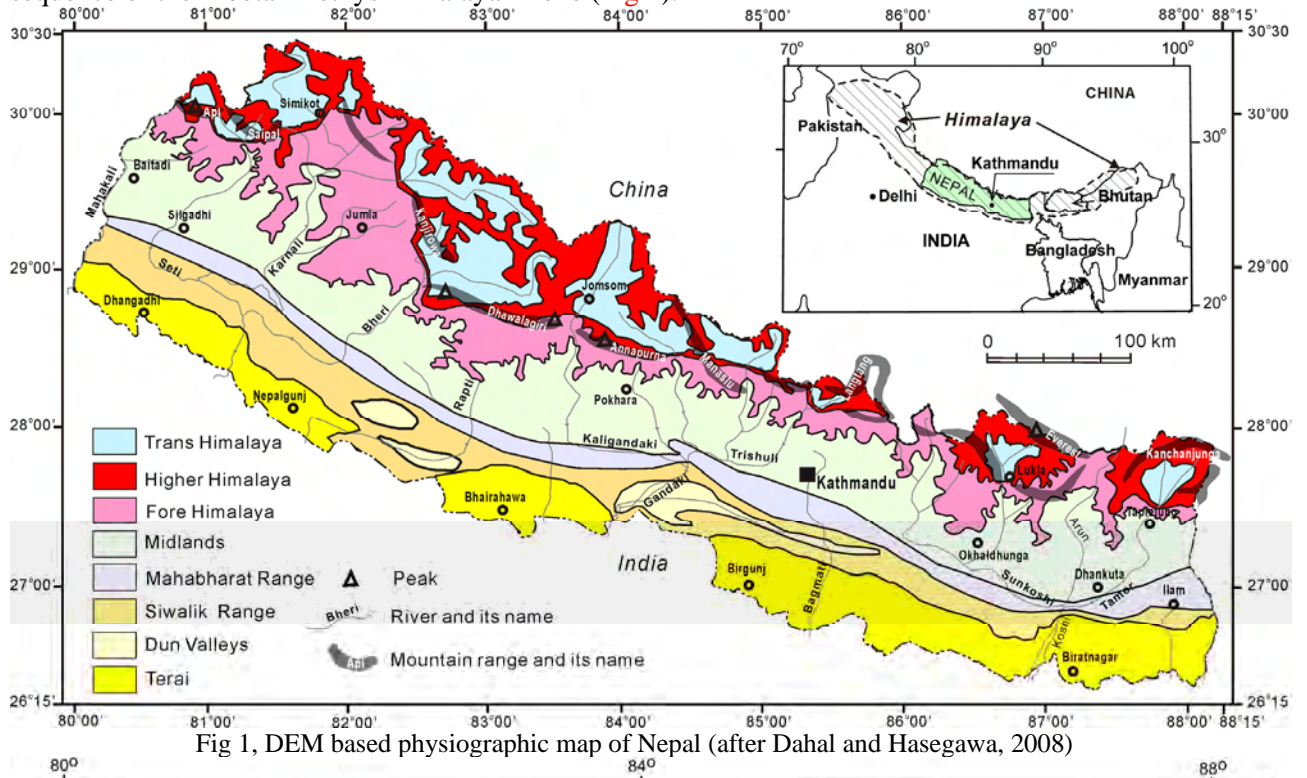


Fig 1, DEM based physiographic map of Nepal (after Dahal and Hasegawa, 2008)

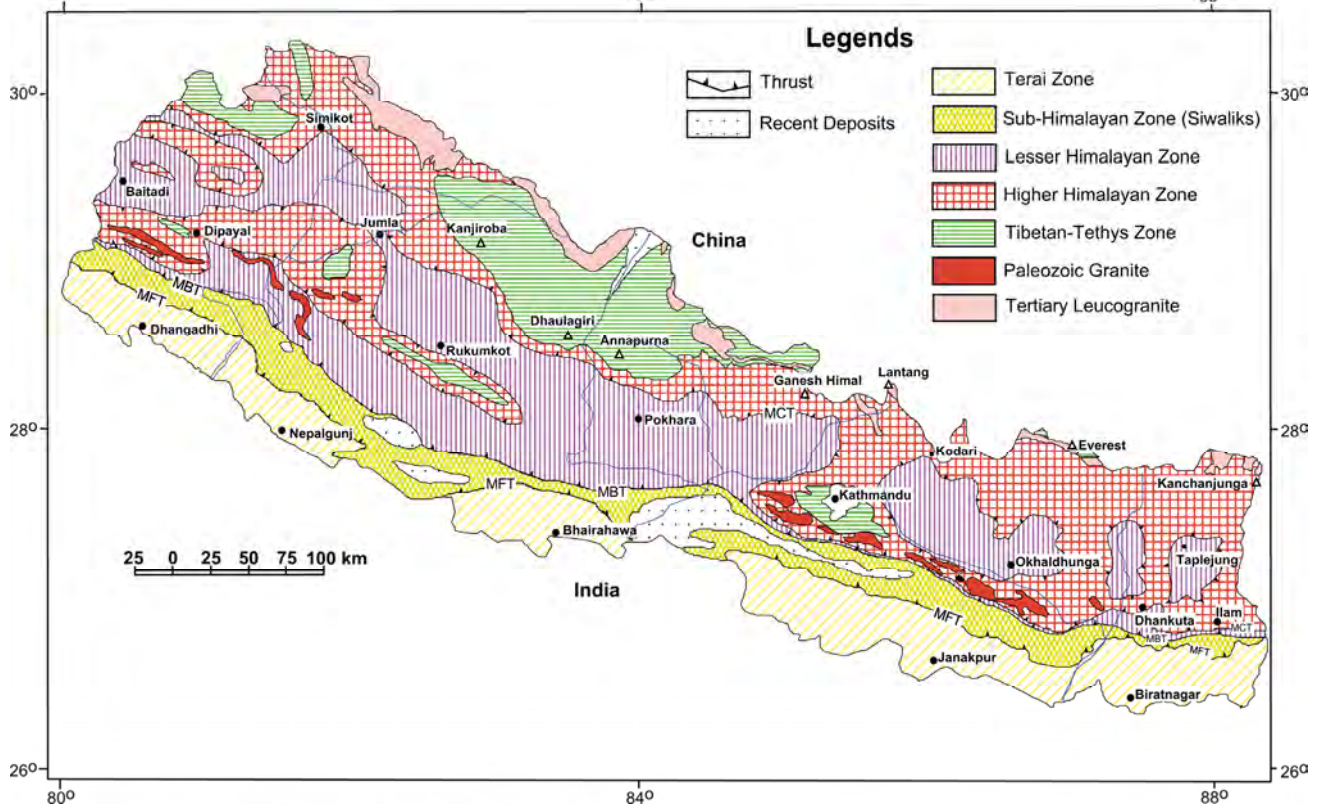


Fig 2, Geological map of Nepal (modified after Dahal 2006)

The Terai Zone is also called as Gangetic Plain and it is the Nepalese portion of the Gangetic Plain that extends from the Indian Shield in the South to the Sub-Himalayan (Siwalik) Zone to the North. The plain is in less than 200 meters above sea level and usually has thick (nearly 1500 m) alluvial sediments. The alluvial sediments contain mainly boulder, gravel, silt and clay. The Sub-Himalaya Zone is also called as Siwalik Zone and it consists basically of fluvial deposits of the Neogene age (14 millions years to 1 millions years old). This Zone extends all along the Himalaya forming the southernmost hill range with width of 8 to 50 km. The Lesser Himalayan rocks thrust southward over the rocks of Siwalik along the MBT. Main rock types of Siwalik are mudstone and sandstone and conglomerate. The rocks of Lesser Himalayan Zone have been transported southwards in several thrust slices. Generally two tectonic sequences namely autochthonous (geologically not moved mass) and allochthonous (geologically moved mass) can be distinguished in this zone throughout the Himalaya. The both sequences of the Lesser Himalaya mainly consist of sedimentary and meta-sedimentary rocks such as slate, phyllite, schist, quartzite, limestone, dolomite, etc, ranging in age from Precambrian to Eocene (2500 ma to 40 ma). There are also some granitic intrusions (Cambrian-Ordovician age, i.e. 570 ma to 450 ma) in this zone. The Higher Himalayan Zone mainly consists of huge pile of strongly metamorphosed rocks. This zone is separated with Tibetan-Tethys Zone by normal fault system called as South Tibetan Detachment System (STDS). It extends continuously along the entire length of the country as in whole Himalaya, and its width varies from place to place (Fig 2). The gneisses, schists, and marbles of the zone form the basement of the Tibetan-Tethys Zones. Miocene (22 ma) leucogranite intrusions are also found this zone. The Tibetan-Tethys Zone lies in northern part of the country and extends to the north in Tibet (Fig 2). This zone is composed of sedimentary rocks, such as shale, limestone, and sandstone, ranging in age from Cambrian to Eocene. In eastern part, there is very few exposure of the Tibetan Tethys Zone. Most of the other great Himalayan peaks of Nepal such as Everest, Annapurna, and Dhaulagiri have rocks of Tibetan-Tethys Zone.

3 ENGINEERING GEOLOGICAL ISSUES IN EACH PHYSIOGRAPHIC PROVINCES

Geologically young mountains of Nepal have wide range of issues related to geological engineering. However, the problems are different in each physiographic province. Brief scenarios of engineering geological problems in various physiographic provinces are given below.

The Terai is made up of recent river deposits and consists of coarse sediment in the north, near to the base of Siwaliks Range and fine in the south, near to the Indian border to Nepal. The elevation of Terai ranged from 65 m in eastern Nepal to 200 m in western Nepal with broad plain area. All rivers of Nepal drain to the Ganga River of India through the Terai. As a result, every year, Terai is facing extreme problems of floods and river bank erosion. Area near to the Siwaliks Range is also confronting problems of debris flows. Moreover, both small and large rivers have shown channel shifting nature in the last 300 years. Riverbeds in the Terai may rise at annual rates of 15 to 30 cm, and satellite imagery clearly shows that the Koshi River in eastern Nepal has shifted about 125 km west of its original course in 250 years (Joshi, 1985). Thus, river channel management during road construction is main geological engineering issue of Terai. In 18 August, 2008, the Koshi River now changed its route and started to flow through the channel before 51 year ago. As a results, nearly 150,00,000 people were displaced from the area both in India and Nepal.

The Siwalik (Churia) Range is made up of geologically very young sedimentary rocks such as mudstones, shale, sandstones, siltstones and conglomerates. These rocks are soft, unconsolidated and easily disintegrable. The Upper Siwalik contains thick beds of conglomerates and they are loose and fragile. Similarly Lower Siwalik and Middle Siwalik have problem from alternating beds of mudstones and sandstone. In such alternating bands, mudstone can flow when saturated with water which results overhanging sandstone beds. Such overhang jointed sandstone beds easily disintegrate into blocks. Similarly, throughout Nepal, the rainfall within Churia Range is normally in the range of 2000 to 2500 mm per year. As a result, geological conditions and the climate render the Churia Range highly susceptible for landslides processes. Basically, rock failures, shallow slides and debris flows are common in Siwaliks.

The Mahabharat Range is belongs to the Lesser Himalayan Zone. It is the most important barrier of the monsoon clouds and it greatly influences the rainfall distribution pattern in Nepal. Almost in whole Nepal, southern face of Mahabharata Range gets extensive rainfall in comparison to Midland. The annual rainfall in Mahabharat Range area is comparatively higher and the frequency of high intensity rainfall is also high. Thus, these areas are getting extensive problem of floods, debris flows and shallow landslides. These events are periodically causing big disasters. Disaster of south and south east Kathmandu in 1993

and disaster of the Mugling-Narayanghat Road of central Nepal in 2003 are examples of such problems. Not only rainfall but geological condition and very steep slopes also plays major role to soil slips and debris flows in the Mahabharat Range. From field observation, it is noticed that the area made up of rocks such as limestone, dolomite marble and granites, the slopes are more stable in the Mahabharat Range whereas area consisting of rocks such as phyllites, slates, intercalation of phyllites and quartzites render the terrain most prone to landslides.

The Midlands also belongs to the Lesser Himalayan Zone and situated at north of the Mahabharat Range. It has a gentle topography compared to Churia and Mahabharat ranges. The slopes are also comparatively less steep than in other zones of Himalaya. Thick soil formations are found in slopes of the Midlands because of deeply weathered rocks. As a result, the slopes are very prone to landslides after intense rainfall. Usually, Midlands is considered as rain shadow zone of the Mahabharat Range, it receives rainfall between 1000 to 2000 mm, but some area has high rainfall record also. Most of the population of Nepal is lived in Midland and this zone is intensively cultivated also. Irrigation system can be found in every terrace on slope as well as on old landslide debris and mismanagement of irrigation canals can be noticed everywhere. These improper agriculture practices generally promote landslides or reactivate old landslides and usually damage whole village of slope (Fig-3).

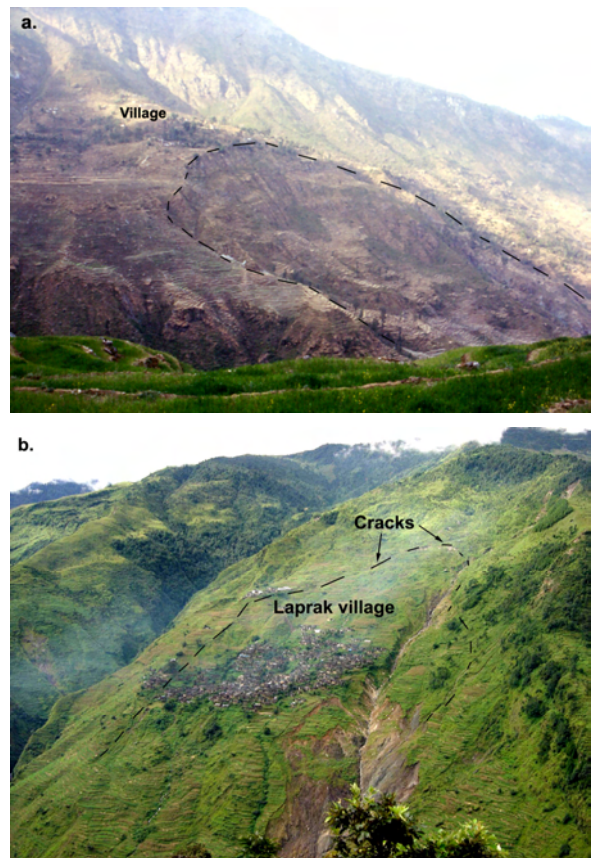


Fig-3 Living with landslides in Nepal, two typical Himalayan landslides

The both Mahabharat Range and Midlands have many numbers of deep seated landslides. Many of them are still active and slow moving creep. Likewise, most of the shallow landslides in Mahabharat Range and Midlands basically occur on deep seated landslides mass (Hasegawa et al. 2008). This phenomenon has been well understood during the study of landslides in major highway of central Nepal (Fig-4). Almost all landslides of 2003 in Mugling Narayanghat Road were occurred on deep seated landslides debris. These deep seated landslides are basically found as huge valley collapsing structures. The slip surface of such landslide has remarkable amount of clay mineral accumulation (Hasegawa et al. 2008). The economical landslide mitigation measures employed in such failure sites were found to have been less effective due to large scale landslides.

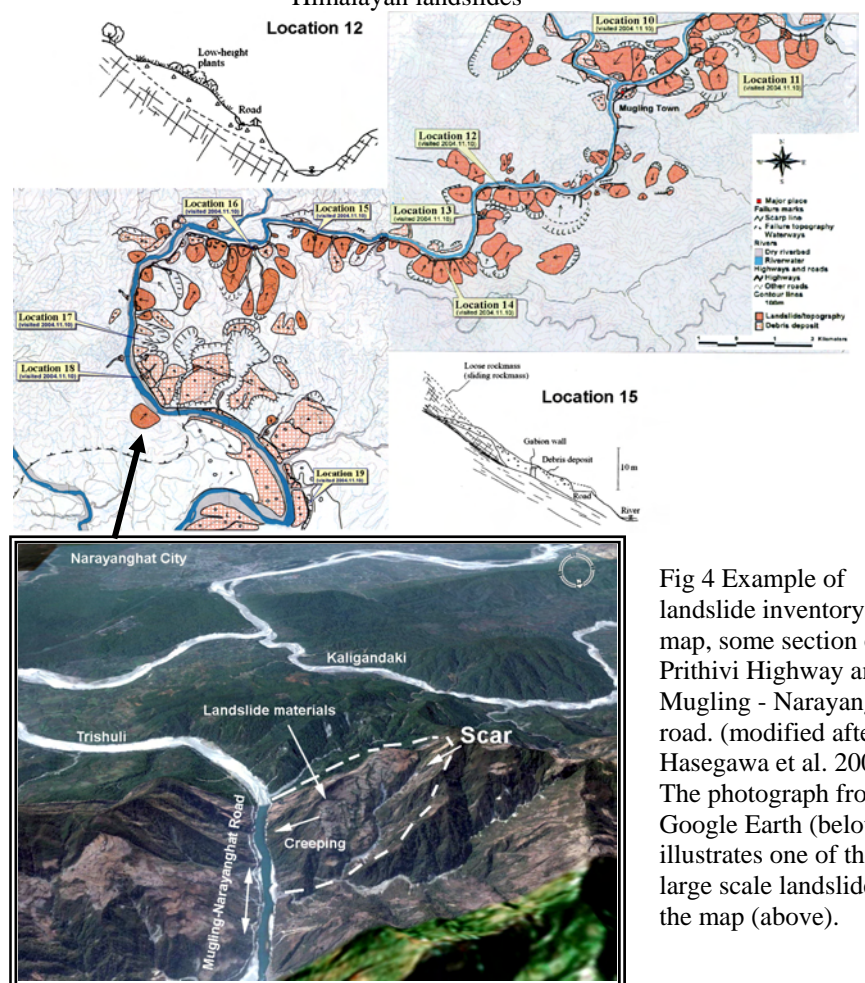


Fig 4 Example of landslide inventory map, some section of Prithivi Highway and Mugling - Narayanghat road. (modified after Hasegawa et al. 2008). The photograph from Google Earth (below) illustrates one of the large scale landslides in the map (above).

The Fore Himalaya is a northern part of Midlands and it is the frontal portion of the Higher Himalaya. Geologically, it is generally belongs to the Lesser Himalayan Zone in many places and in some places it is the Higher Himalayan Zone. Thus, main rock types of this province are phyllites, schists, marble, quartzites, and gneisses. Tectonically, this zone is very active and uplifting at a high rate and the topography is steep and rugged. Similarly, like the south faced slope of the Mahabharat Range, the Fore Himalaya also gets high rainfall in the range between 2000 to 3500 mm. This province is also another vulnerable area for landslide occurrence, but because of less soil on steep slope, mainly rock related failure problems are very frequent. Deep seated landslides are also common in this zone. Some landslide dams can be also noticed in narrow river valleys of this province (Fig-6).

The Higher Himalaya province is the highest area of Himalaya. It includes all elevated peaks and their slope exceeding 5000 m in altitude. Geologically, this province belongs to the Higher Himalayan Zone and the Tibetan-Tethys Himalayan Zone in some extent and main rock types of this zone are gneisse, schist, marble and quartzite. Vertical or steeps rocky slopes are very common in this province. Usually, the southern face of province generally receives high precipitation. Mainly, in this province, there is no or little soil cover on slopes and very large rock related failure phenomena are very common. For example, mega landslides of Lete village in the Kaligandaki River which is believed to be responsible to dam the Kaligandaki River for a long time and because of this landslide dam the Kaligandaki River channel is broad and braided in Larjung, Jomsom and Kagabeni area of Mustang. Many glaciers of the Nepal Himalaya are now in retreating phase and there are many lake at terminal point of glaciers. Thus, Glacier Lake Outburst Flood (GLOF) is another engineering geological issue of Higher Himalaya.

The province behind (north) the Higher Himalaya is called Trans Himalaya. Geologically, this province belongs to the Tibetan-Tethys Himalayan Zone. This area is situated in the rain shadow zone of the greater Himalayan Range. This zone has average annual rainfall very low in comparison to the Midlands and the Fore Himalaya. Thus soil related landslides are less frequent but debris flow in a snow fed stream is quite common. The river bank made of alluvial and glacial moraine possesses bank failure problem.

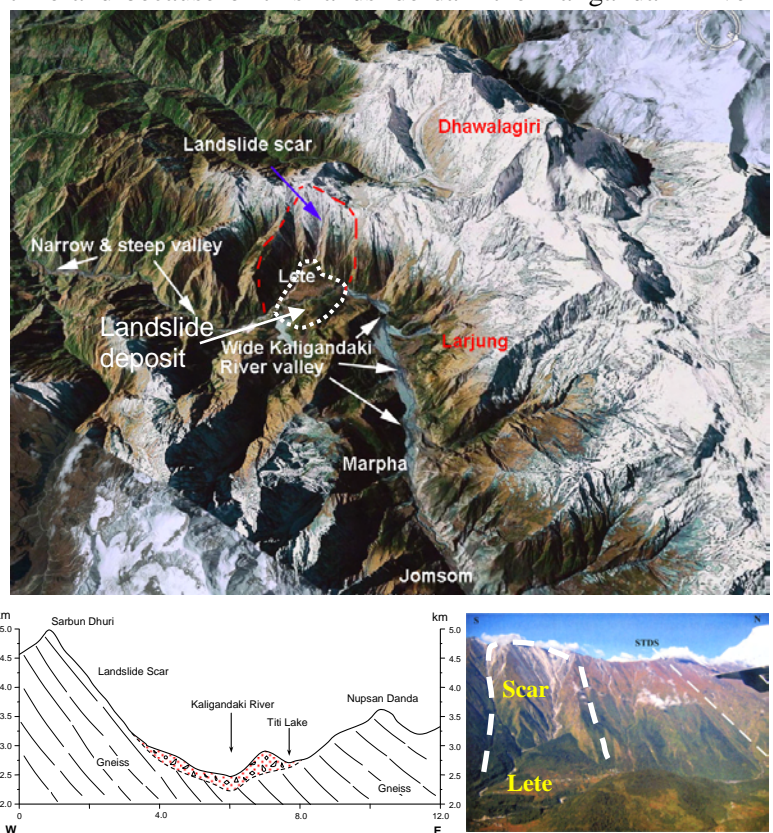


Fig-6 Huge landslides in the Lete village. The broad and braided channel of the Kaligandaki River can be noticed on upstream from Lete whereas downstream has steep and narrow valley. The photographs on lower right of figure also shows rock slide scar.

4 RAINFALL AND LANDSLIDE RELATIONSHIPS IN NEPAL

Processes and characteristics that contribute to landslides in Nepal can be arranged in four categories: (i) geological causes (weak, weathered, sheared materials, and contrast in permeability of materials); (ii) morphological causes (fluvial, erosion of slope toe, tectonic uplift, erosion of marginal sides); (iii) physical causes (intense rainfall, prolong or exceptional precipitation, earthquake, and snowmelt); and (iv) human causes (deforestation, irrigation, mining, road construction, artificial vibration, water leakage, land use changes).

Until 2007, for the Himalaya, no generalized studies exist for landslide and debris-flow initiating rainfall thresholds although these mountains have tremendous landslide problems compared to other parts of the world. In early 2008, considering rainfall as a main factor triggering landslides in Nepal, Dahal and Hasegawa (2008) established relationships between landslide occurrence and rainfall characteristics in the form of empirical equations. These empirical relationships of rainfall with landslide occurrence described a threshold rainfall necessary for triggering landslides in Nepal. The method employed by Dahal and

Hasegawa (2008) in establishing the rainfall thresholds is similar to that by other researchers (e.g., Caine, 1980; Larsen and Simon, 1993; Guzzetti et al. 2007) for such estimations in different parts of the world.

Dahal and Hasegawa (2008) described rainfall threshold for Nepal in two different approach: intensity-duration threshold and normalized rainfall intensity threshold. They defined intensity-duration threshold as:

$$I = 73.90D^{-0.79} \dots\dots\dots (1)$$

Where I is hourly rainfall intensity in millimeters (mm/hr) and D is duration in hours. According to this threshold relation, for rainfall events of shorter duration, such as below 10 hours, a rainfall intensity of 12.0 mm/hr is necessary to trigger landslides, while an average precipitation of less than 2 mm/hr appears sufficient to cause landsliding if continued for more than 100 hours. Similarly, if 24-hour rainfall exceeds 144 mm, there is always risk of landslides in Nepal.

Dahal and Hasegawa (2008) also analyzed the landslides and the corresponding rainfalls respect to the mean annual precipitation (MAP). The ratio between the critical rainfall of the event and the mean annual precipitation of the site is defined as normalized critical rainfall (NCR), and it is expressed in percentage. By normalizing rainfall intensity with NCR, Dahal and Hasegawa (2008) expressed following threshold for landslides in Nepal:

$$NI = 1.10D^{-0.59} \dots\dots\dots (2)$$

Where NI is normalized rainfall intensity (hr^{-1}) and D is duration in hours. The threshold relation indicates that for rainfall events of 1-day, a normalized rainfall intensity of 0.17 hr^{-1} (i.e. 17% of MAP) is required to trigger landslides, while a normalized rainfall intensity of less than 0.07 hr^{-1} (7% of MAP) appears sufficient to cause landslides if continued for more than 100 hours. Similarly, an analysis of the 55-year record of landslides and rainfall events in the Himalaya has suggested that many landslides occurred under the influence of a wide range of rainfall durations (5 hours to 90 days).

5 CONCLUDING REMARKS

Highly dynamic physical processes dominate the mountainous terrain of Nepal, and therefore, implementing infrastructure development projects is a challenge. Construction, maintenance and rehabilitation of infrastructure under the unique Himalayan condition require innovative and more pragmatic approach compared to less critical terrains in other parts of the world. Many earlier projects have faced various problems during survey, design and construction phases, and in the process invaluable experience has been gained during the last five decades. New concepts, approaches and techniques appropriate to this unique Himalayan terrain are gradually emerging. These techniques and experience are important and far-reaching, and may be applicable in similar regions of the developing world. Over the years Nepal has gained a significant amount of experience in landslide studies and stabilization, survey, design and construction of roads, tunnels and dams; in the fields of hazard and risk assessment, low-cost road (green roads) engineering; and slope maintenance.

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