# Roadside Slope Failures in Nepal during Torrential Rainfall and their Mitigation

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## Abstract

Nepal is a mountainous country situated in the heart of the Himalaya. The Himalaya is also famous worldwide for its very active tectonics. In Nepal, over 80% of the rainfall occurs within a short three months during the monsoon period and extreme rainfall events are very common such as over 400 mm of rainfall can occur within 24 hours. Thus, these geological and climatic factors make the mountain slopes of Nepal most susceptible for rainfall triggered landslides. In Nepal, to provide transportation facilities to all people, in last ten years, road construction projects are considered as a major part of infrastructure development and the growth of the roads shows exponential increase from 376 km in 1950 to 15,308 km by 2000 within a period of 50 years. In which nearly half of total road length is earthen roads. These road construction and maintenance programs are widely affected by both shallow and deep seated landslides triggered by monsoon rainfall. This paper comprehensively deals with roadside slope failures during torrential rainfall events in major road of Nepal such as Tribhuvan Highway, Siddhartha Highway, Prithivi Highway, Arniko Highway, Dhulikhel-Sindhuli Road, Mugling-Narayanghat Road, Dharan-Dhankuta Road, Pokhara-Baglung Road, Beni-Jomsom Road, as well as some rural roads. Similarly, in this paper, mitigation measures used to stabilize the slopes are also discussed with some illustrations.

**Keywords:** Rainfall, Himalaya, landslides, mitigation, bioengineering

## Introduction

Nepal is a mountainous country situated in the heart of the Himalaya. The Himalaya has one of the most dynamic and fragile mountain landscapes. The seasonal monsoon rains, intense but improper land use practices both for cultivation and construction ensure that the Nepalese Himalayas are among the most unstable landscapes worldwide. The inherently weak geological characteristics of rocks and soils have made the Himalaya fundamentally a very fragile mountain (Upreti 2001). The Himalaya is very vulnerable to natural and common hazards such as landslides, debris flows, and soil erosion primarily triggered by extensive rainfall of monsoon. The combination of the weak rock and thick soil cover and monsoon climate makes each physiographic zone of Nepal very hazardous. 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 (rainfall) with soil and rock is indispensable. One interesting obsession associated with landslide calamities of Nepal is that it always happened during monsoon season only. So it is better to define rainfall as the prime triggering factor of each landslide.

Landslides triggered by rainfall occur in most mountainous landscape (Iverson, 2000; Hungr, 2003). They pose a significant natural hazard and they have a high damaged potential (Brenner, 2003). In Nepal, this phenomenon is being experienced in every monsoon. In the year 2003, landslides triggered by rainfall extensively damaged the Mugling-Narayanghat road of central Nepal. Total 213 landslides are noticed in this road section. In which more than 50% of landslides belong to flow-like nature (Dahal and Kafle, 2003).

## Road construction practice in Nepal

In Nepal, growth of road shows exponential increase from 376 km in 1950 to 15,308 km by 2000 within a period of 50 years. In which nearly half of total road length is earthen roads (Fig. 1 and Fig. 2). Nepal Road Standards classifies roads as follows:

- National Highway connecting length and width of the country

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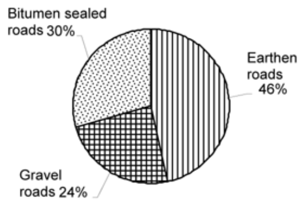


**Fig. 1.** Road types in Nepal (DoR, 2000)

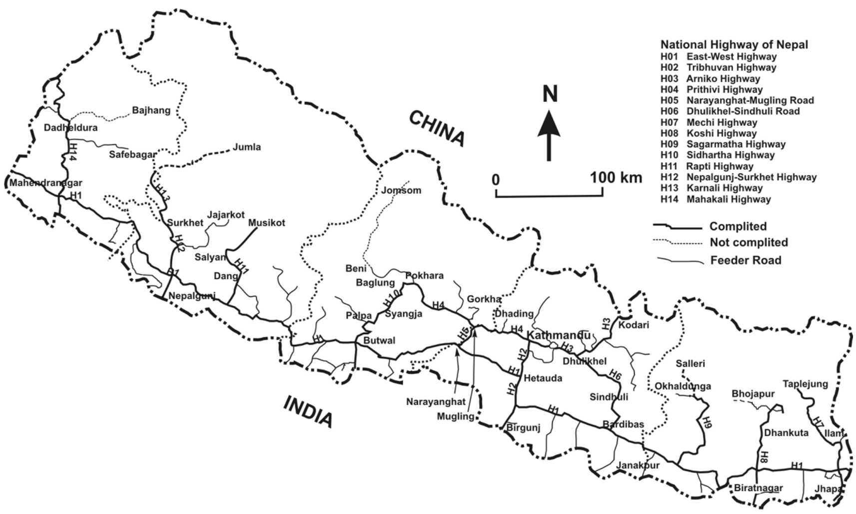


**Fig. 2.** Road network in Nepal, data source DoR 2000

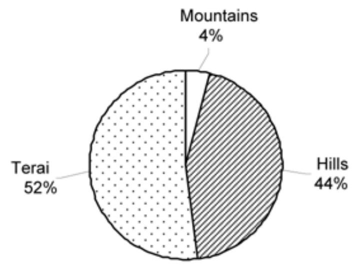


**Fig. 3.** Road distribution in Nepal by physiographic region (DOR, 2000)

- Feeder Road providing access to important trade centers and district headquarters from the national highways
- District Road providing access to trade centers within the district as well as district headquarter
- Urban Road within the city area
- Rural Road to provide access to rural settlements and agricultural centers

The national highways and feeder roads are included in Strategic Road Network (SRN) under the jurisdiction of the Department of Roads (DoR). Nearly one third of total road length is incorporated with SRN. Other remaining two thirds of total roads are considered as district roads, rural roads, urban roads, agricultural roads which are under the jurisdiction of Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) and local bodies (District Development Committee, Village Development Committee and Municipalities).

Construction of roads on mountains of Nepal (Fig 3) possesses quite complicated issues because of steep slopes, thick soil profile, weak rock mass and torrential rainfall of monsoon. In the recent days, road construction practices are extensively increased in Nepal from central level to district and then village level. Highways construction practices are also increased. Nepalese Government is also giving due importance for highway maintenance.

Major highway of Nepal like Prithivi Highway, Tribhuvan Highway, Siddhartha Highway, and East-West Highway are continues in maintenance phase wisely. New highway like Dhulikhel-Sindhuli Road, Chhinchu-Jajarkot Road, Surkhet-Jumla Road and Beni-Jomsom are also in construction phase. Similarly it is not a surprising fact that more than 40% Village Development Committees (VDCs) of all over Nepal have Users Committee for rural road construction. International donor agencies are also giving intense priority for rural road construction in community level. These road construction and maintenance program is widely affected by landslide and debris flow triggered by monsoon rainfall. The failures also vary in severity and losses. Roadside slope failures have not commonly resulted in major loss of life, because most catastrophic failures

**Table 1.** Existing road construction practices in Nepal (modified after Adhikari 2004)

| *Methods* | *Generic Guidelines* | *Landslide Occurrence* |
|---|---|---|
| Labor intensive method | Applied for construction of early roads in Nepal<br>Labor groups employed as labor contract, no work contracts<br>No heavy equipment used except work tools<br>Mostly full cut roads<br>Structures and embankments minimized<br>Side casting of surplus material permitted<br>Blasting for rock breaking<br>Embankment and fills compacted with light equipment<br>Equipment used for pavement construction | High Risk of Landslides<br><br>Need extensive costly mitigation measure |
| Conventional Mechanized Road Construction Practice | Applied in highways, feeder roads and urban roads<br>Earthwork equipment used for cut, slope trimming and embankment construction<br>Mechanized compaction of backfill and embankments<br>Laborers used for minor works – drainage, slope finishing, subgrade preparation etc.<br>Full range of equipment used for pavement construction<br>Blasting for rock breaking permitted<br>Large contractors employed for construction | High Risk of Landslides<br><br>Need extensive costly mitigation measure |
| Labor-Based Road Construction Method | Mostly used for district roads and feeder roads<br>Only light equipment used, no heavy equipment used<br>Small local contractors used for civil work contracts<br>Maximum use of local laborers for works<br>Limited blasting permitted for rock breaking<br>Large scale and long distance haulage not practical | Medium Risk of Landslides<br><br>Need extensive mitigation measure |
| Low-cost Environment-friendly and Participatory (LEP) Method | Stage construction of road formation (1.5m, 2.5m, 4.0m) in combination with bioengineering<br>Only local laborers used through community based organizations<br>Wages equally distributed, no profit retained by community based organizations<br>No contractors may participate<br>Balanced cut and fill principle – no haulage of surplus material<br>Bioengineering measures as an integral part in each stage<br>Natural compaction principle – no artificial compaction<br>Only local material used except some gabion wires<br>Use of cement discouraged<br>Blasting for rock breaking not permitted<br>Road formation out cambered for sheet flow – no side drains<br>Equipment may be used only for gravelling and pavement<br>Prevailing method for rural and agricultural roads<br>Also applicable for construction of highways and feeder roads<br>Method is inherently poverty focused and uses poorest people | Generally destroyed by monsoon rainfall so seasonal road<br><br>Shallow failures are prominent<br><br>Needs routine care by community |

have occurred in less populated areas. Economic and financial losses are, however, substantial. Generally shallow failure occurred along the roadside, both in uphill as well as downhill slope, are major problems of roads of Nepal. These problems are excessive both in major highways and in rural roads.

The road construction practices in Nepal are often guided by desire of the donor agencies and interest of local political leaders. It is partly attributed by the lack of uniform and mandatory national standards and guidelines. Through enforcement of the public works directives (PWD) in 2001 some degree of uniformity has been achieved in the project implementation practices. Table 1 lists existing road construction practices adopted for the construction of roads in Nepal. Keeping the views of the situation, this paper deals with rainfall patterns in the area of highways, feeder roads and rural roads, and failures triggered by rainfall. The paper also highlights the existing mitigation practice for roadside failure. Similarly, possible low budget mitigate measures functional in roadside slopes are also evaluated for major highways, rural roads and capillary roads of Nepal. Major roads like Dhulikhel-Sindhuli Road, Siddhartha Highway, Prithivi Highway, Narayanghat-Mugling Road, Dharan- Dhankuta Road, Pokhara-Baglung Road, Malekhu-Dhading Road, Arniko Highway, Beni-Jomsom Road, Sanfebagar-Martadi Road, Khodpe-Bajhang Road as well as some rural roads like Chatara-Barahchhetra Road (Sunsari), Hile-Pakhribas Road (Dhankuta), Gorkha-Aarughat Road (Gorkha), Balephi-Jalbire Road (Sindhupalchowk), Jomsom-Kagbeni-Muktinath Road (Mustang) etc are investigated. Some capillary roads of Palpa, Syangja, and Bhojpur are also taken into consideration (see Fig 2).

## Roadside landslides triggered by rainfall

For the prediction of rainfall triggered landslides, the concept of hydrological landslide-triggering thresholds has been already developed in some extent. Similarly, a correlation between rainfall intensity, rainfall duration and landslide events are also already established (Caine, 1980 and Terlien, 1998). Moreover, the influence of rainfall on landslides usually depends on landslide dimensions, kinematics, material involved, etc. Experiences shows that shallow failures are usually triggered by comparatively short intense storms (Campbell, 1975; Pasuto and Silvano 1998, Crosta, 1998; Wieczorek et al, 2000; Hungr, 2003; Jakob. and Weatherly, 2003;

**Fig. 4.** Krishnabhir Landslide in October 2004

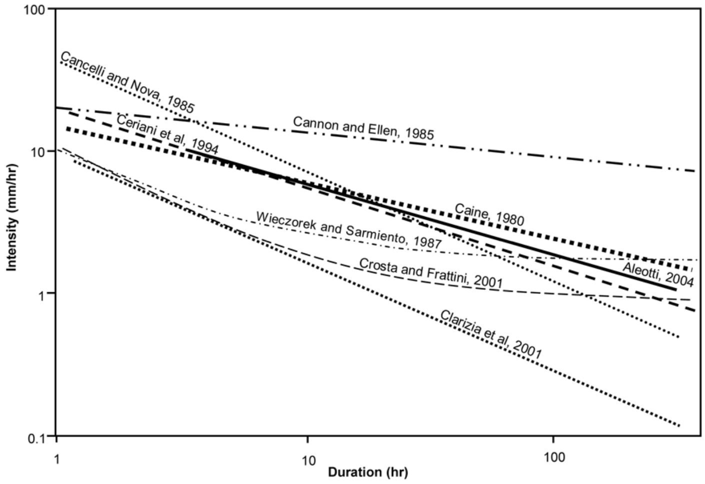


**Fig. 5.** Rainfall intensity thresholds for triggering landslides illustrated in some of literatures (modified after Aleotti, 2004).

Crosta and Frattini, 2003; Xie et al, 2004; Aleotti, 2004; Wen and Aydin, 2005; Kim et al 2004) whereas most of the deep-seated landslides are affected by long-term variation of annual rainfall as well as daily rainfall which has to last at least some couple of years (Bonnard and Noverraz, 2001; Hong et al, 2005). In Himalayan context, shallow landslides are associated with monsoon brought torrential rainfall (Dahal and Kafle 2003; Poudel et al 2003; Gabet et al 2004; Khanal and Watanabe 2005). Not only shallow landslide, but also deep-seated landslides are also usually associated with the monsoon rainfall. Many roadside slopes along the highways consist of considerable numbers of deep-seated landslides which are in prolong creep during torrential rainfall. For example, a large and well known landslide of the Prithivi Highway, named as Krishnabhir Landslide (Fig 4), occurred after some days of intense precipitation, in the Trishuli River valley (Lesser Himalaya) at the beginning of mid of August 2000 and blockade the Prithivi Highway, main entry route of Kathmandu, total 11 days. Because of low cost mitigation measures and “wait and see” principle, the highway was blocked many times since 2000 and it was stabilized in 2005. Better to say, in 2005, there was no blockade report from the Krishnabhir Landslide.

The shallow landslide on slope that generally flows down to slope in very high velocity is found to be most devastating landslide in Nepal. Such landslide is fundamentally called as debris flow (Hungr et al 1984; Coussot and Meunier 1996; Hungr et al 2001; Wen and Aydin 2005) and recently also portrayed as flow like landslide (Dai et al 1999, Iverson, 2000, Hungr et al 2001, Hungr 2003, Dai et al 2003, Jakob and Weatherly, 2003, Malet et al 2004). Some attempt has been done to describe the threshold value of Himalayan rainfall triggered landslides (Caine and Mool 1982, Dahal and Kafle 2003, Gabet et al, 2004, Khanal and Watanabe 2005) but it is found to be insufficient because of extremely varied site condition. Thresholds rainfall for triggering landslides is one of the debatable topics since last 25 years. It was N. Caine who first published a paper in 1980 about the threshold rainfall value for landslides. After that many attempts were done to establish the threshold value, in global context as well as in regional context.

From the study of published research works (Fig 5), it is realized that generally two types of thresholds can be established for rainfall to trigger landslide (Aleotti, 2004), empirical thresholds and physical thresholds. Empirical threshold basically based on statistical analysis of relationship between rainfall and landslide occurrences (Campbell, 1975; Caine, 1980; Larsen and Simon, 1993, Crozier 1999; Guzzetti et al 2004) whereas, physical threshold usually described by the help of hydrologic and stability models which consider parameters like relationship between rainfall and pore water pressure, suction, infiltration, slope morphology and bedrock structures etc (Montgomery and Dietrich, 1994; Wilson and Wieczorek, 1995; Crosta, 1998; Terlien, 1998, Crosta and Frattini 2003). Requirement of detail knowledge of boundary conditions is one of the main constraints of physical model (Aleotti, 2004). In the case of the Himalaya some empirical methods have been discussed by some of researcher to establish threshold of rainfall for failures in Himalaya (Khanal and Watanabe 2005).

As already mentioned, Himalaya is very vulnerable to natural and common hazards such as landslides, debris flows, and soil erosion primarily triggered by extensive rainfall of monsoon (Fig. 6 and Fig. 7). The combination of the elevated peaks, steep slopes, weak rock and thick soil cover over intact bedrock along

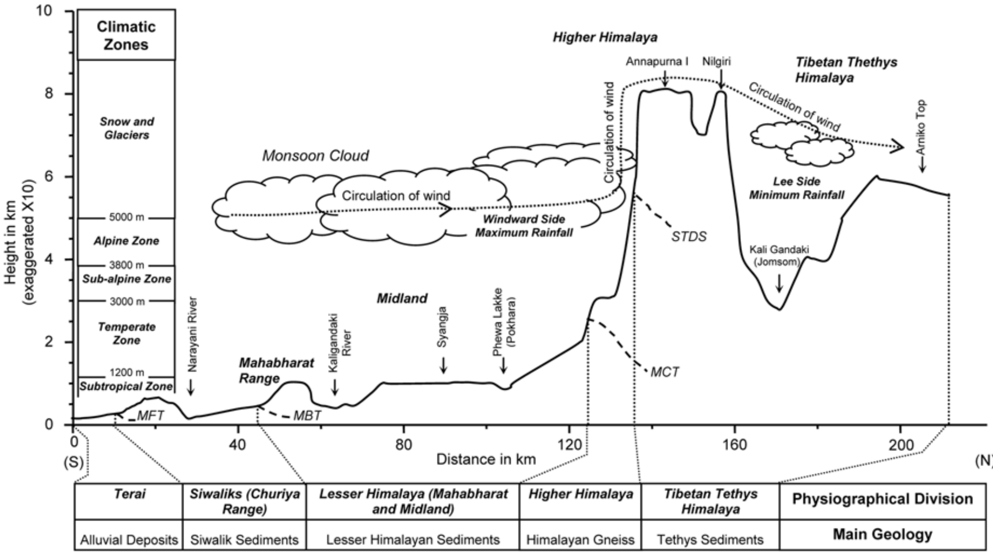


**Fig. 6.** Cross section of Nepal Himalaya, illustration from Narayanghat-Pokhara-Jomsom section, MCT (Main Central Thrust), MBT (Main Boundary Thrust) and MFT (Main Frontal Thrust) make Himalaya tectonically active (Stöklin 1980) and dynamic mountain of world. The Siwaliks, Lesser Himalaya and Higher Himalaya get torrential monsoon rainfall because of orographic effect of elevated mountains (modified after Dahal 2006).

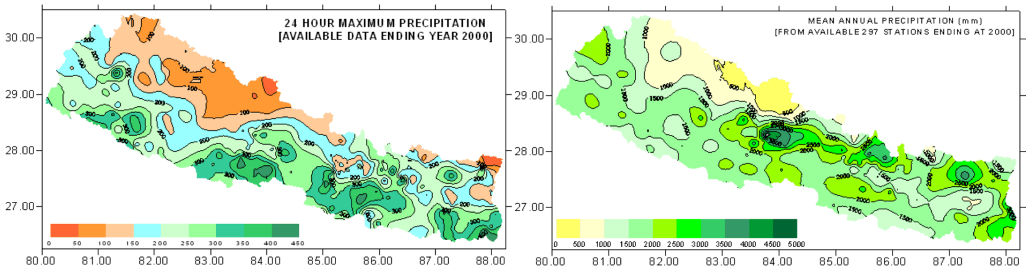


**Fig. 7.** Mean annual precipitation map and highest 24-hour precipitation (mm) map of Nepal (DHM 2003)

with the monsoon climate makes each physiographic zones of Nepal very hazardous. Moreover, central Nepal, including Kathmandu, gets high intensity of rainfall than other part of Nepal. Study shows that, in the case of southern hills of Kathmandu, if cumulative rainfall of 24-hours is more than 260 mm, flow like landslide or debris flow can be occurred but for shallow debris slide, this value can be ranged between 230 to 250 mm (Dahal and Kafle 2003). In other part of Nepal, also if the soil is thick colluvium deposit, this value of threshold rainfall is 230 mm (Khanal and Watanabe 2005). The study of rainfall pattern of Nepal reveals that more than 80% of rainfall occurs in monsoon season and all landslide events occur only in this period. Landslides distribution map also represent the relation of rainfall and landslides (Fig 8). Major highways like the Prithivi Highway and Siwalik stretch of the East -West Highway and Muglin-Narayanghat Road were severely damaged by monsoon rainfall since 1993 to 2004.

Extreme rainfall of 24 hours of various parts of Nepal shows that some places it reach up to 300 mm per day (Fig 9 and 10) and studies shows that this value is enough for triggering landslide on steep slope (¿30o) of Lesser Himalaya. However, in Nepal, rainfall data analysis is a tough job because of low density of rain gauge station and lack of hourly recorded data. The intense rainfall that occurred in Chitawan (central Nepal) on July 2003 resulted a series of landslides affecting steep roadside slopes of the Muglin-Narayanghat Road, all having similar characteristics (Fig. 11). These gravitational mass movements occurred suddenly, generally extending for tens or even hundreds of meters and damaged almost 80% of total highway stretch (36 km).

Many stretch of Siddhartha Highway also severely damaged by rainfall triggered landslide. Same problems are also observed many feeder roads and district roads like Balephi-Jalbire Road (Sindhupalchowk),

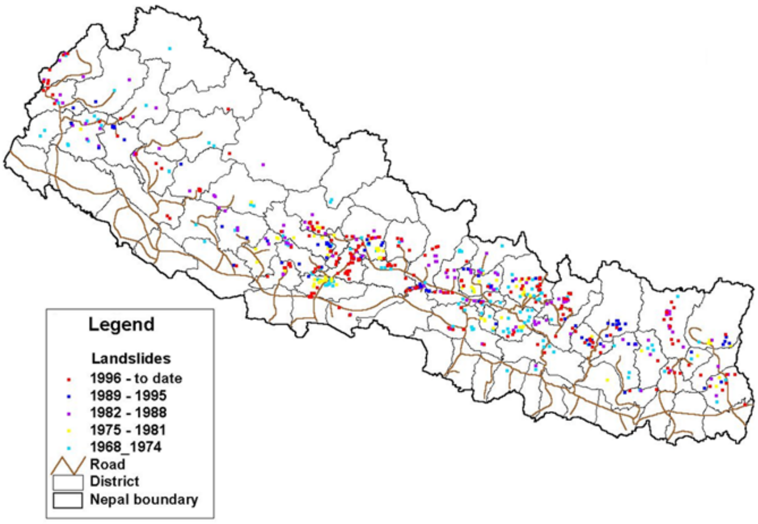


**Fig. 8.** Landslides distribution in Nepal (after LRA/DoLIDAR/Scott Wilson, 2002)

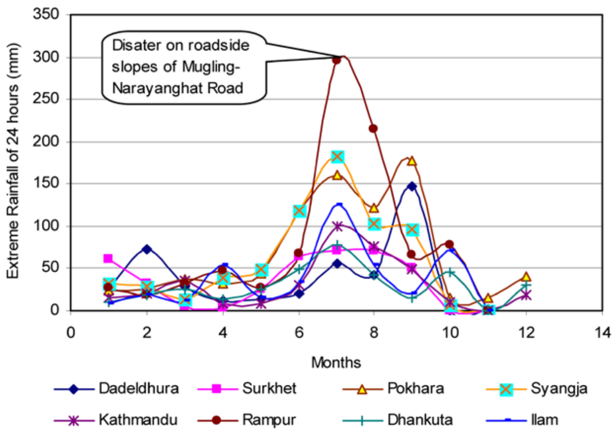


**Fig. 9.** Extreme Rainfall of 24 hours in 2003 at various part of Nepal, (Data source DHM, 2003)

Beni-Jomsom Road, Jomsom-Kagbeni- Muktinath Road (Mustang), Gorkha-Aarughat Road, and Bhakunde-Dumri Bhanjyang (Syangja).

Based on classifications proposed by Varnes in 1978, Hutchinson in 1988 and Cruden et al (1996), landslides which occurred in 2001, 2002 and 2003 can be classified as translational landslides, rotational landslides, followed in many cases by a flow-like landslide or debris flow. Nevertheless, some landslides of highways are very large landslide of complex nature (e.g. Krishnabhir, Prithivi Highway, see Fig. 4). Failure surface of translational landslides on slopes is generally at a depth of 2–4 m and appears to affect whole hill slope. In fact, such small scale landslides are noticed in large scale landslide mass (Fig 12) as seen in Mugling-Narayanghat Road. Detachment is generally seen on rock and soil contact surface also (Fig. 13). Rotational slides are generally seen on thick colluvial deposit as well as residual soil where water on cut slope was not properly managed (Fig. 14). Flow-like landslides are even observed in Jomsom area (Jomsom-Kagbeni-Muktinath Road) where annual rainfall is only 250 mm. Many part of the Narayanghat-Mugling Road are damaged due to flow like landslide (see Fig 11) and debris slides. These flow like landslide are generally initiated in small area at top of hill or head of gully and flow with extremely high velocity and erode its path which finally rich with high debris load and damaged every thing on its path. These flows generally have very shallow depth (Fig 15). Most of the flow-like landslides triggered by rainfall were appeared on roadside slopes of Nepal where slope was mainly between 30° and 40°, with failures rarely recorded on slopes of $< 20°$. The materials involved in all flows are very similar mainly gravel silt (USBR, 1963) of colluvial origin. Regarding to rainfall infiltration behavior and soil moisture characteristics during rainy season on roadside slopes, it can be suggested that primary failure mechanism is related to increasing water content as a result of downward movement of a wetting front. Natural

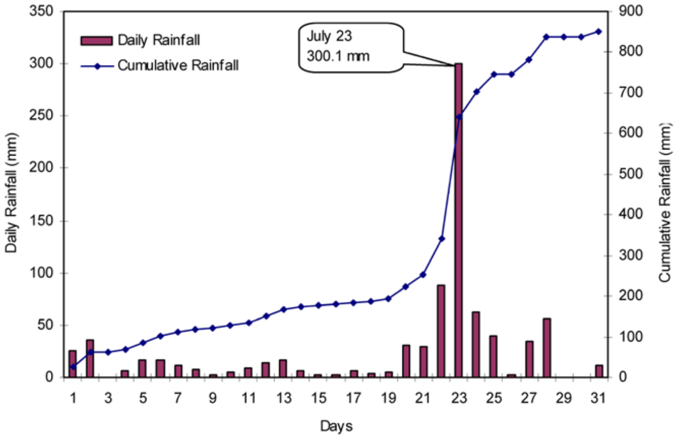


**Fig. 10.** Rainfall pattern of Thankot (west of Kathmandu) in the year 2002 (Data source DHM, 2003)

**Fig. 11.** Debris flow in Mugling Narayanghat Road at Jalbire village

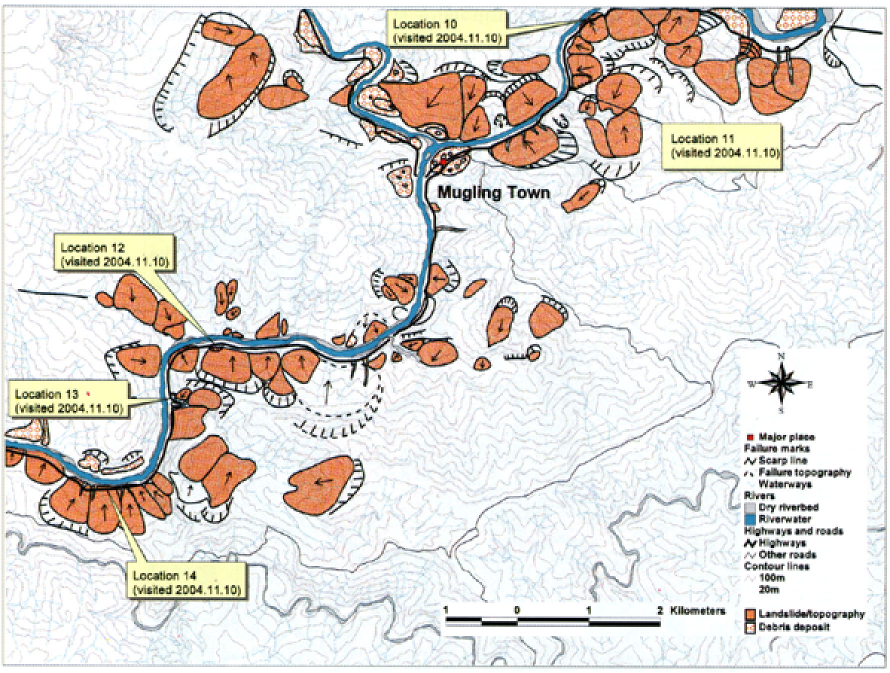


**Fig. 12.** Landslides inventory map along Mugling Narayanghat Road around Mugling town (after Yatabe et al 2005)

piping in colluvial soil is another factor noticed during field visit.

## Site investigation methods in practice

In Nepal, still standard method of site investigation is not developed. In most of cases site specific geological problems are investigated without presence of geologist and many parameters are missed. As a result, most of mitigate measures become unsuccessful after implementation. An integrated approach is necessary to understand failure mechanism and to conceive affordable solutions for mitigation of rainfall triggered landslides. In every case, problems on roadside slopes are only due to poor management of surface and subsurface water. Similarly, sometimes technical person also could not understand the cause and mechanism of failure and he always wishes to construct more rigid walls. Such examples could be seen at the Siddhartha Highway (approx. ch. 1+200 km from Devid Fall, Pokhara, name of landslide is Kattike Mool ), where damaged walls are in continue replacement process from gabion wall to concrete masonry wall. But concrete masonry was again

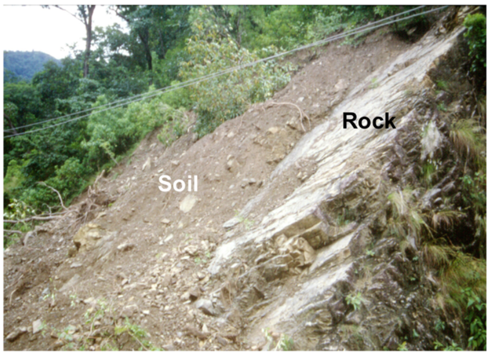


**Fig. 13.** Translational slides observed in Chatara-Barahchhetra rural road

**Fig. 14.** Rotaional slides observed on cut slope at chainage 1+250, Balephi-Jalbire rural road

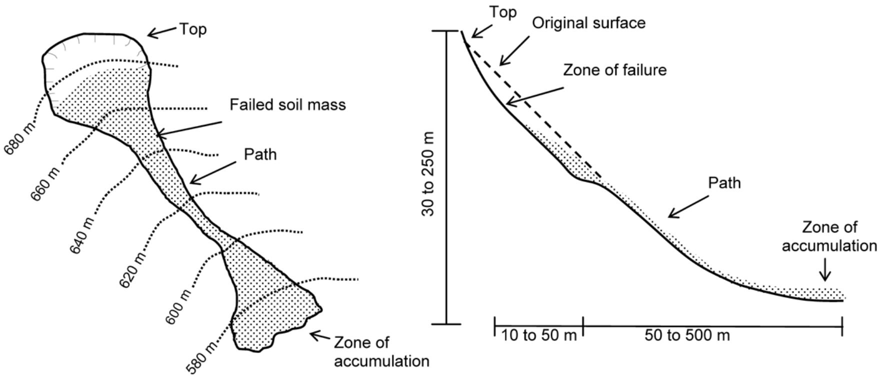


**Fig. 15.** Diagrammatic indication of a typical flow like landslide feature on roadside slopes of Nepal

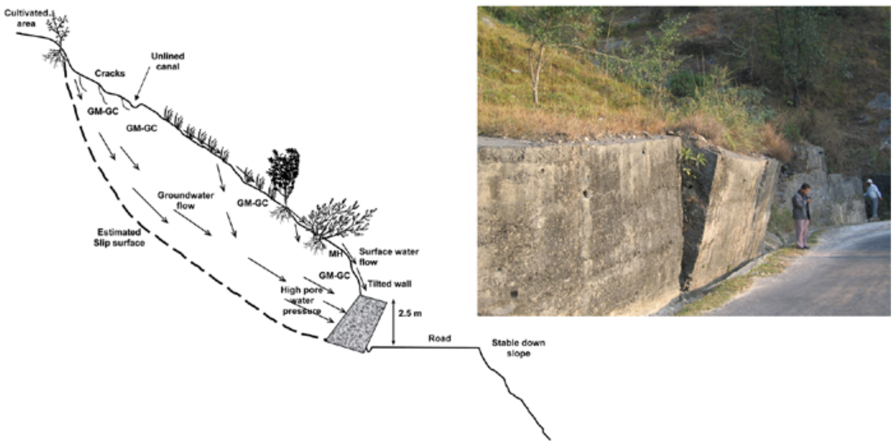


**Fig. 16.** Schematic diagram of Kattike Mool landslide and damage concrete masonry wall at km 1+200, Sidhhartha Highway, Pumdi Vumi, Pokhara, Kaski

displaced and damaged in 2004 (Fig 16). Only one problem on this site is ground water but there is not any structure which can manage groundwater. So proper understanding of geological problems is essential. Detailed topographic survey is necessary at landslides area. An engineering geological survey is also necessary along road. But such surveys are not in practice in district and rural roads. Even in highways, such surveys do not consider as a prime investigation works.

As we know, geotechnical investigations like test pitting, subsoil sampling, field and laboratory testing to obtain index properties and strength parameters of soil material should perform for each landslide before

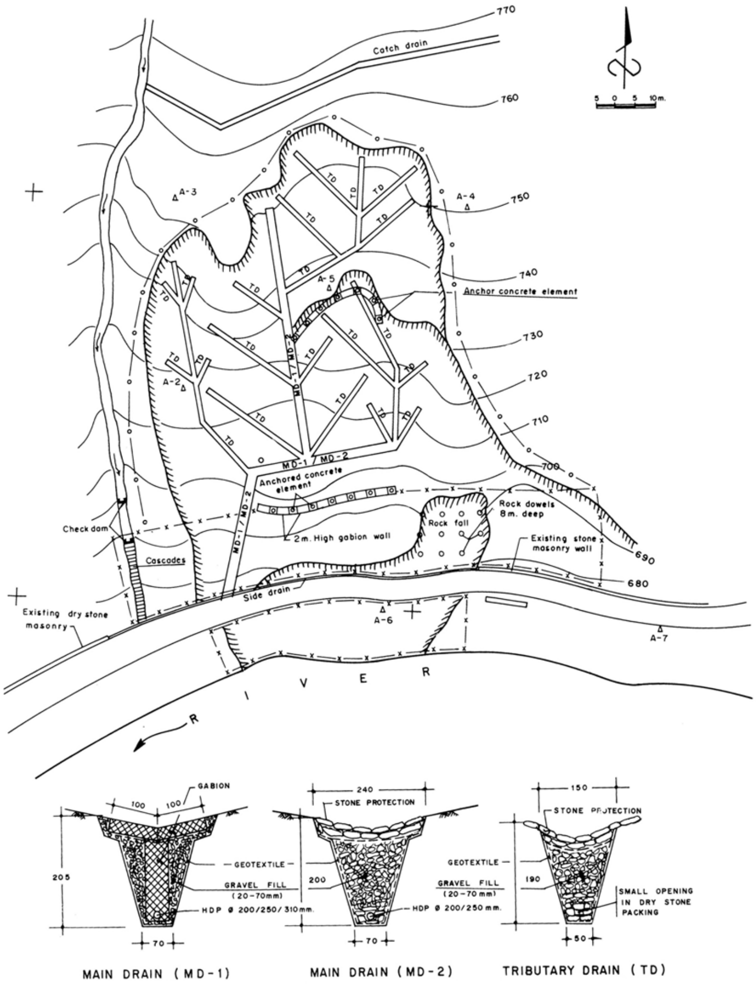


**Fig. 17.** ood approach of water management on roadside slopes of Arniko Highway (DOR, 1991)

implementation of mitigation measure. But such investigations are almost not in practice for district roads and rural roads. Clear understanding of groundwater flow pattern in cut slope is necessary, but we do nothing for this aspect during road construction. Fortunately, in some district roads and in Arniko and Prithivi highways, groundwater flow patterns are well recognized and well managed during implementation of mitigation measures (Fig 17).

## Mitigation Measures

### *Drainage Measures*

There are few well accepted practices of drainage measures in roads of Nepal. Mainly Dhulikhel-Sindhuli Road, Siddhartha Highway, Prithivi Highway, Dharan-Dhankuta Road, Pokhara-Baglung Road, Arniko Highway, and East-West Highway have relatively good management of surface runoff at cut slopes and landslides. In these roads, surface runoff of up to $1m^3/s$ has been drained out with lined catch drains and riprap channels designed for minimum 25 years return period. Drainage of subsurface/surface water has been managed using french drains (depth 1.5 m to 2.5 m). General effective depth of a network of french drains is down to lower saturation level from ground surface. Excellent performance of french drains were observed at both landslides and cut slope of Arniko Highway, particularly from km 62 to km 87 (Fig 17). But unlined catch drain around the cut slope at km 4+000 of Dhulikhel-Sindhuli Road possessing adverse effect on slope (Fig 18). Similarly, many retaining wall and toe wall constructed without managing subsurface water at different chainage of Beni-Jomsom Road have been damaged extensively in 2004.


**Fig. 18.** Improper use of unlined catch drain and generation of shallow failure after rainfall at km 4+000, Banepa-Nepalthok Road

**Table 2.** Vegetative structures practiced on roadside slopes of Nepal

| | | |
|---|---|---|
| 1. Grass seeding or broadcasting | 2. Palisades | 3. Shrub planting |
| 4. Diagonal lines of grass planting | 5. Tree planting | 6. Vegetated riprap |
| 7. Down ward lines of grass planting | 8. Bamboo planting | 9. Brush layering |
| 10. Chevron lines of grass planting | 11. Fascines | 12. Live staking |
| 13. Herring bone lines of grass planting | 14. Live check dam | 15. Horizontal lines of grass planting |
| 16. Random pattern of grass planting | | |

### *Structural Support Measures*

In roadside slopes of Nepal, structural support measures are also applied in combination with drainage and bioengineering measures. Various types of walls such as gabion, stone masonry, composite masonry etc. have been using to mitigate failure. Support structures such as rock bolts, earth anchors, anchored walls etc. are also found to be used in Arniko and Prithivi highways.

### *Bioengineering Measures*

In Nepal, comprehensive bioengineering work (Table 2) has been carried out during the last 25 years and large experience has been collected in slope stabilization using vegetation (Howell, 1999; Dahal, 2001; Lewis 2001; Florineth et al, 2002, Gray and Leiser, 1982). A combination of terracing, mulching, grass planting, tree planting, gabion-netting, edge rounding, top soil spreading, reseeding and complementary measures such as palisades, live stakes, hedge layers etc. are generally found to be applied in roadside slopes of Nepal.

## Summary and conclusions

Landslides and debris flows triggered by torrential monsoon rainfall events are common in Nepal Himalaya. Such events are highly localized along both old and recently constructed roads and losses and damages are extremely high. Study shows that average 200 to 240 mm of rainfall per day is enough to create small to medium size landslides on roadside slopes of Nepal. Therefore, at present, road planners, consultants and executors in Nepal have now realized the need of an integrated approach for investigation, analysis, design and construction of mitigative structures on landslides. But still Department of Roads of Nepal does not have single geologist as an employee. As a result, proper site investigation for engineering geology always lacks. As an immediate action, to protect roadside slopes by rainfall triggered landslide, draining of slopes through a network of surface, near-surface and deep horizontal drains need to be emphasized. Structural measures should be applied where drainage alone is considered insufficient to improve slope stability up to an acceptable factor of safety. For low cost slope stabilizing measures, bioengineering measures need to be considered as an integral component of stabilization system.

Further studies are needed to establish landslide-rainfall thresholds so that early warning system could be developed. For vigorous analysis of landslide-rainfall thresholds, it is very urgent to establish automated rainfall gauging stations around the country that can measure hourly rainfall data precisely.

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