

Quest for disaster-resilient roads in the Himalaya

Shubhra Sharma, S. P. Sati, Y. P. Sundriyal, Vikram Sharma and Harsh Dobhal

Mountain roads are important lifelines and the most critical means for connectivity in the Himalayan villages of India. However, the inherent geological, geomorphological, ecological and climate fragility of the terrain warrants critical scientific investigations for the roads to sustain the vagaries of nature. Further, the increased frequency of extreme events with the ongoing climate change increases the potential impact of disasters. This note highlights the major challenges and issues faced with the ongoing road-widening projects in the country. It cautions against the uniform standard of road widening and the need to increase sensitivity towards appreciating the terrain fragility.

In recent times, slope instability associated with the Himalayan roads in India has increased, resulting in serious damage to life and property. For example, Himanchal Pradesh, India, experienced multiple slope failures such as the tragic Kinnaur (Chaura village), Nahan–Kumarhatti and Pandoh (near Mandi town) in 2021. Similar incidences were observed in the adjoining Uttarakhand Himalaya. Such tragic incidences, certainly raised concern about the stability of the Himalayan roads and thus, the safety of the local inhabitants. It is pertinent to understand whether these road-proximal disasters are the geomorphic expression of slopes to extreme weather events or the result of unscientific tampering without adequate understanding of the Himalayan geology and structures.

Infrastructure expansion is occurring at a dramatic rate across the globe and the Himalaya is no exception. Paved roads have increased by ~12 million km worldwide since 2000, with an additional ~25 million km projected by mid-century^{1,2}. Majority of the roads are being built in developing nations, including many ecologically sensitive regions such as the Himalaya which is exceptional in terms of wilderness, biodiversity, ecosystem services, and rare and endangered species³. The success of Himalayan road projects lies in early assessment of the risk posed by potential geohazards, particularly the slope instability caused due to excavation of steep slopes. This can be achieved with focused scientific studies of the terrain before route alignment, identification of hazard-prone locations, as well as proactive and persistent planning of slope management following road construction.

During May 2017 in Hanoi, Vietnam, around 160 leading financiers, decision-makers, ecologists and social-development specialists deliberated upon the strategies to limit the environmental impacts of

roads. It was observed that too much funding is being earmarked for the initial construction of ambitious new road networks and too little for their ongoing maintenance⁴. Further, there is no denial that a few roads are adequately engineered for the challenging local conditions, but there are large number of roads which suffer from ill-planned construction. According to a World Bank study, typically 15–30% (and in some cases ~60%) of road funding in developing nations is lost to cartels and corruption¹.

Besides road stability, an equally important factor is the rapid penetration of roads into many of the world's ecologically sensitive and biodiversity hot spots (national parks and wildlife sanctuaries). From 1993 to 2009, the extent of global wilderness which houses rare and endangered species has declined by about 10% (ref. 3). One of the reasons for this is climate change. The Himalaya is witnessing significant temperature changes since the 20th century. The warming trend during the first half of the 20th century was about 0.16°C per decade, which later doubled to 0.32°C per decade from the beginning of the 21st century⁵. Incidences of forest fire in the Himalaya have increased significantly, which besides weakening the soil cohesiveness (due to heat-induced dryness) is linked to increasing incidences of cloud bursts (soot acting as cloud condensation nuclei)⁶ and further cascading into landslides and flash floods.

In Uttarakhand, the Government of India has launched an ambitious Rs 12,000 crores road-widening project called the Char Dham Pariyojna (CDP). Under this project roads (~900 km) are being widened (two-laned widening with paved shoulders), with no environmental clearance required (administratively), since these roads were fragmented into 53 segments having stretches <100 km for which Environment

Impact Assessment (EIA) is not mandatory. Nevertheless, the 100 km rule is ineffective, considering the fact that the Himalayan roads traverse through abrupt rise in the altitude gradient, thus trespassing the diverse geological and ecological niches within short distances (Figure 1). With the focus of the current road-widening project on increasing the road width, the critical aspect of disaster resilience and environment has been ignored, rendering it highly prone to slope instability. Studies demonstrate that there is a positive correlation between road width and slope instability causing associated environmental damage in the hilly terrain^{7,8}. With the chronic landslides remaining untreatable, in spite of the advancement in engineering measures. Hypothetically, even if an assumption is made about future stability of the slopes, the increased and unregulated tourist (vehicular) inflow would become detrimental to the health of the already stressed Himalayan ecosystem. Hence, there is an ongoing tussle between the development planners and environmentalists, which is rather ironic. Without addressing the ecological and environmental stability of the geologically/geomorphologically fragile slopes riddled with chronic landslides, it would be difficult to achieve the desired objective of providing sustainable disaster-resilient roads.

The Uttarakhand Himalaya lies in the earthquake zones IV and V, and experiences innumerable earthquakes of varying magnitudes. As a result, the rocks are highly fractured, fissile and at places pulverized. Various scientific studies and Government-sponsored, landslide-related projects have already warned about the vulnerability of slopes in Uttarakhand Himalaya⁹. However, little is achieved in terms of stabilization and prevention of landslides¹⁰. The slope stability becomes particularly critical in the Higher Himalaya

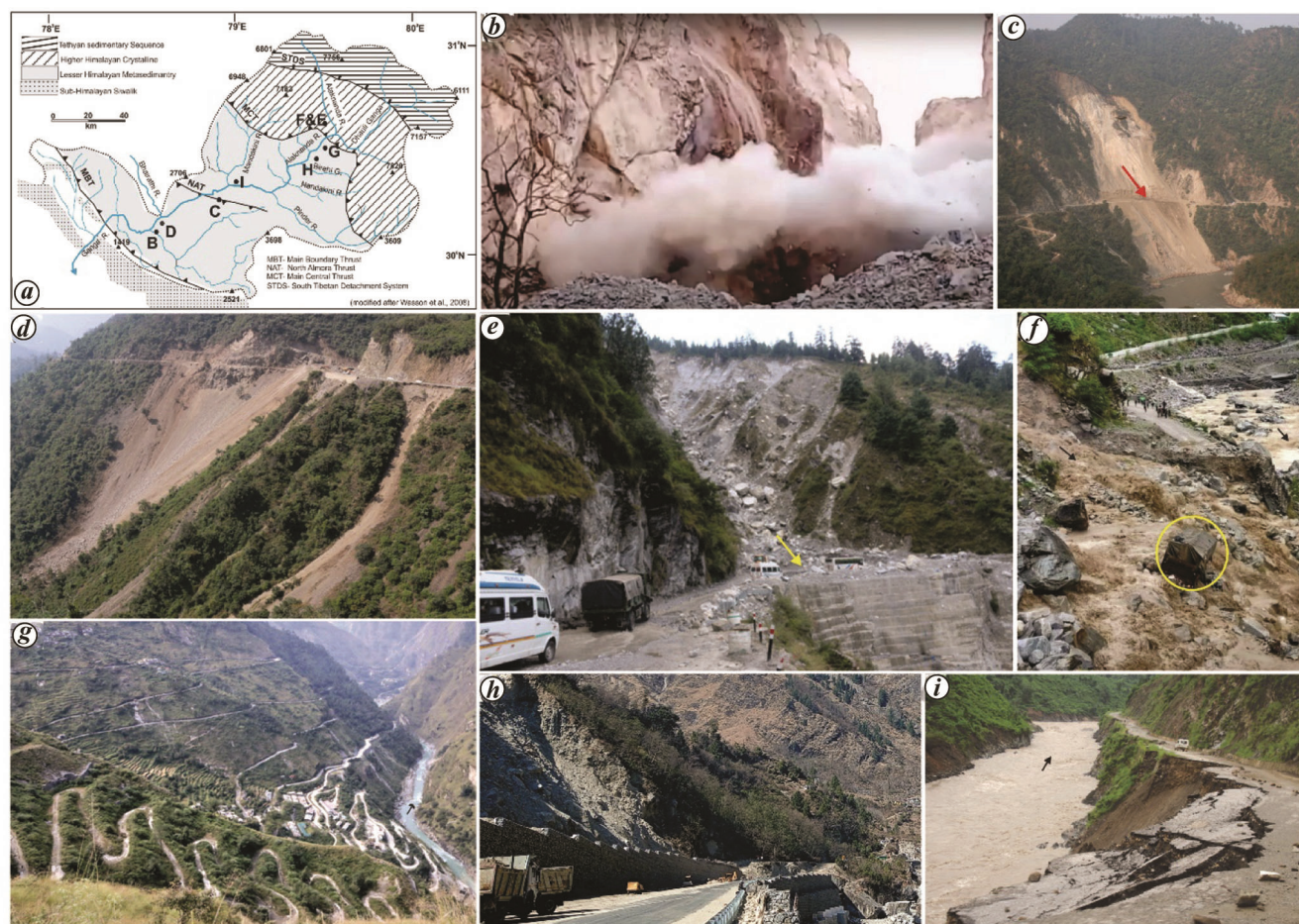


Figure 1. **a**, Geological and structural map of the upper Ganga catchment with locations of the field photographs marked. **b**, Jointed Karol limestone with solution cavities around Totaghati being blasted using dynamite during road widening along NH-58. This is one of the most unstable zones along this highway. **c**, The chronic Kaliyasaur landslide (~100 years old) is currently being bypassed because various agencies failed to provide a long-lasting solution for its treatment. **d**, Excavated debris near Sakni Dhar, like many other places, thrown down-slope without adequate measures to prevent it from damaging the forest and bulking the riverbed. **e**, The infamous Tangni landslide which was triggered after the July 1970 Alaknanda flood. The rocks which are dominated by dolomite with subordinate slate and quartzite are highly sheared due to their proximity to the Main Central Thrust (MCT). **f**, The May 2021 cloud burst-induced flash flood wiped away a part of NH-58 near Lambagar. **g**, NH-58 between Helong and Joshimath, where the road negotiates extreme altitudes within a distance of ~10 km. **h**, Landslide conservation measure near Lambgar to protect the road from frequent debris avalanches during monsoon. Note the proximity of dried Alaknanda river (due to barrage upstream). **i**, The damaged Kedarnath road after the June 2013 floods due to toe erosion. The road is not only constructed proximal to the flood level, but also on unconsolidated colluvium.

(north of the Main Central Thrust), where the roads are threatened by frequent debris flows, snow and rock avalanches and flash floods. The region also acts as a sediment hot spot because of the sequestration of large volumes of para-glacial sediments left behind by receding glaciers in the recent geological past¹¹. These sediments are mobilized during extreme precipitation events and also during the glacial lake outburst floods¹². The roads constructed proximal to the flood levels are one of the worst hit during such disasters. Unfortunately, instrumental records of the Himalayan floods are short (<50 years in length), spatially discontinuous and strongly biased towards the anthropogenically modified

landscapes, particularly by the hydropower barrages and human encroachment of flood plains^{13,14}. Without long-term flood magnitude and discharge data (beyond instrumental record), it would be extremely difficult to predict the behaviour of the Himalayan rivers.

Considering that extreme events are most likely to increase due to climate change, one of the potential impacts would be increased incidences of landslide hazards. Studies suggest that under the warm earth scenario, the cumulative rainfall (not rainfall duration) is likely to have an overriding influence on future landslide thresholds¹⁵. A similar hypothesis was proposed by Mishra and Srinivasan¹⁶ during the June 2013

disaster. According to them, 'high cumulative rainfall may be more important than a cloud burst to trigger the catastrophic lake burst'¹⁶. This will lead to large-scale sediment mobilization from paraglacial zones. It would increase the probability of damaging roads at multiple locations by flood overtopping and lateral toe erosion by hyper concentrated flows, as seen in the Mandakini valley Uttarakhand¹⁴.

The Himalayan terrain is complex with enormous geological and ecological variability over short distances. Thus, it would be hazardous to opt for a uniform standard of road widening (as observed in the CDP). It is therefore difficult to sustain developmental activities unless our roads

are environment-friendly and disaster-resilient. Assessment of the terrain by detailed EIA should be mandatory prior to execution of road projects by independent experts with established scientific credentials and experience of working in the Himalaya. This would significantly help in providing environment friendly and disaster resilient roads in an ecologically fragile Himalayan terrain.

1. Alamgir, M., Campbell, M. J., Sloan, S., Goosem, M., Clements, G. R., Mahmoud, M. I. and Laurance, W. F., *Curr. Biol.*, 2017, **27**(20), R1130–R1140.
2. Laurance, W. F., *Trends Ecol. Evol.*, 2018, **33**(8), 568–571; <https://doi.org/10.1016/j.tree.2018.05.007>.
3. Laurance, W. F. *et al.*, *Nature*, 2014, **513**(7517), 229–232; doi:10.1038/nature-13717.
4. Laurance, W. F. and Arrea, I. B., *Science*, 2017, **358**, 442–444.
5. Yan, L. B. and Liu, X. D., *J. Earth Ocean Atmos. Sci.*, 2014, **1**, 13–28.
6. Sagar, G. K. *et al.*, *Atmos. Environ.*, 2021, **246**, 118–123; <https://doi.org/10.1016/j.atmosenv.2020.118123>.
7. Larsen, M. C. and Parks, J. E., *J. Br. Geomorphol. Group*, 1997, **22**(9), 835–848.
8. McGuire, T. M. and Morrall, J. F., *Can. J. Civ. Eng.*, 2000, **27**(3), 523–532.
9. Poonam, Rana, N., Ray, P. K. C., Bish, P., Bagri, D., Wasson, R. J. and Sundriyal, Y., *Geomorphology*, 2016, **284**, 41–52.
10. Sati, S. P., Sharma, S., Sundriyal, Y. P., Rawat, D. and Riyal, M., *Nat. Hazards Risk*, 2020, **11**(1), 887–905.
11. Sati, S. P. *et al.*, *J. Asian Earth Sci.*, 2014, **91**, 125–136.
12. Rana, N., Singh, S., Sundriyal, Y. P. and Juyal, N., *Curr. Sci.*, 2013, **105**(9), 1209–1212.
13. Sundriyal, Y. P. *et al.*, *Episodes*, 2015, **38**(3), 179–188.
14. Shugar, D. H. *et al.*, *Science*, 2021, 300–306.
15. Alvioli, M. *et al.*, *Sci. Total Environ.*, 2018, **630**, 1528–1543.
16. Mishra, A. and Srinivasa, J., *Curr. Sci.*, 2013, **105**(1), 1351–1352.

ACKNOWLEDGEMENT. S.S. acknowledges Institute of Eminence (IoE) grant, Banaras Hindu University for publication fee.

Shubhra Sharma and Vikram Sharma are in the Department of Geography, Institute of Science, Banaras Hindu University, Varanasi 221 005, India; S. P. Sati is in the Department of Basic and Social Science, College of Forestry, Ranichauri, Tehri Garhwal (VCSGUUHF, Bharsar), India; Y. P. Sundriyal is in the Department of Geology, HNB Garhwal University, Srinagar, Garhwal 246 174, India; Harsh Dobhal is in the School of Media and Communication Studies, Doon University, Dehradun 248 001, India.*

**e-mail: shubhra@bhu.ac.in*