



YEG-Article-9/2025

Landslide-damaged infrastructure at Lesser Himalayas: An engineering geological assessment of Lohar Gali Landslide in the Muzaffarabad, AJK, Pakistan Khuram Shehzad

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1. Preliminary information on the landslide

Like other Asian countries, Pakistan continues to face numerous natural and human-made threats that endanger the health and safety of its citizens. In particular, the changing climate is shaping the landscape while geological hazards around Muzaffarabad (Kashmir) vary in severity, with the level of vulnerability depending on the type of hazard and potential. Many researchers have revealed the vulnerability to landslides and proposed different models to predict mass movements to reduce potential damages (Pradhan and Siddique 2019).

Engineering geological conditions of the Lohar Gali Landslide (Muzaffarabad) are varied and require a thorough study of geohazards nearby. Hence, this article aims to investigate and analyze geohazards-prone areas and assess their vulnerability, investigate slope failures, identify the triggering mechanism of layered rocks, analyze surface image geometrical configurations, and evaluate the engineering geological condition of slopes using field operations and remote sensing mapping (ArcGIS) techniques. The initial findings indicate that the foliated Hazara Formation, being easily collapsed, is particularly susceptible to the geological/geomorphological conditions that triggered the Lohar Gali landslide. Landslide hazards are destructive phenomena that can cause massive property damage, loss of life, disturbance of social and economic norms, and also harmful environmental impacts. These hazards can be characterized by factors such as location, frequency, intensity, and possibility of occurrence (Becker et al. 2022; Ward et al. 2020; Paul 2020; Zhao et al. 2023). According to Becker et al. (2022), Lahusen et al. (2020), and Zhang et al. (2019), landsliding occurs due to various climatic, geomorphological and geological reasons, such as climate change, heavy rainfall, rapid glacier melting and earthquakes. Additionally other multiple factors contribute such as topography of the area, soil and rock types, fractures and bedding planes, and moisture content.



Landslide risk differs from landslide hazard as it depends on the presence of vulnerable elements. While landslide hazard relates to natural environmental characteristics, landslide risk focuses on components that landslides could affect, including the population, built environment (structures, infrastructure, and properties), natural environment and its ecological services, and economic factors (Guzzetti 2000; Rossi et al. 2019; Salvati et al. 2010; Strouth and McDougall 2021; Strouth and McDougall 2022).

Additionally, Smith et al. (1992) divided landslide risk into two parts: direct impact and indirect impact. He defined direct impacts as loss of life, injuries, and costs of building or house reconstruction and indirect impacts as business losses reduced income, and illness. The risk of landslides increases in the spring time as melting glaciers lead to higher runoff which is a situation worsened by climate change. Landslide assessment predicts where and when landslides are likely to occur, how quickly they might develop, and the potential scale of slope failure (Guzzetti et al., 1999). Risk is defined as the potential loss of life, injury, destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity (UNDRR, 2016). It is important to study natural factors such as geology, steep terrain, erosion caused by river water flow, unstable rock conditions or loose soil mass, excessive rainfall, and seismic events that play vital roles in slope instabilities (Pathak and Nilsen, 2004).

In 2014, the Lohar landslide displaced a huge mass of 618 meters in length and 318 meters in width, depositing a significant volume of debris that, if remobilized could block infrastructure (roads, water supply) for extended periods as well as posing a potential hazard to buildings, houses, and downstream areas. Geographically, the Lohar Gali landslide is located along the main highway connecting Muzaffarabad to Mansehra (coordinates 34°20'36.39" N and 73°26'21.17" E). This article focuses on the geohazard assessment of the Lohar Gali Landslide and its potential impacts on infrastructure, and also ongoing risk to the village above and communities along the Neelum River floodplain below. This particular aspect has not yet been thoroughly investigated in the landslide-prone district of Muzaffarabad, Pakistan. This landslide has been a site of multiple events over the past four months (late 2024) significantly causing the tragic loss of many lives.

The region including Muzaffarabad, is tectonically active, contributing to landslides like the one in Lohar Gali triggered by movement on two active fault lines - branches of the Muzaffarabad and Jhelum faults. A large volume of debris material quickly flowed from the roadside to the river bed. Ongoing movement is observable as slopewash and minor debris together with occasional slumping events on the adjacent marginally stable slopes (Figure 1). The loss of roads and resulting traffic congestion have caused significant financial losses and transportation challenges. During



heavy rainfall, the Public Works Department performs temporary repairs, but a permanent solution remains elusive. Additionally, the Lohar Gali landslide, considered an old slide, is believed to have originated in the mid-1980s, with risk of further movement increasing after the 2005 earthquake. The Lohar Gali Landslide is complex and consists of old landslide debris, colluvium, and underlying bedrock. The steeply dipping slope is comprised of highly sheared slates, phyllites and shales which formed around 545 million years ago (Late Precambrian). The shales and phyllites have a fine-grained texture with color ranging from greyish-green to blackish. The upper part of the escarpment slope is adjacent to the main highway and consists of overburden and overhanging boulders. Furthermore, the escarpment comprises colluvium and shales that dip downward at an inclination of 60° to 70° . These rocks have been weakened over time due to earthquakes and repetitive rainfall-induced slope failures, as well as undercutting by the river at the toe of the slope.

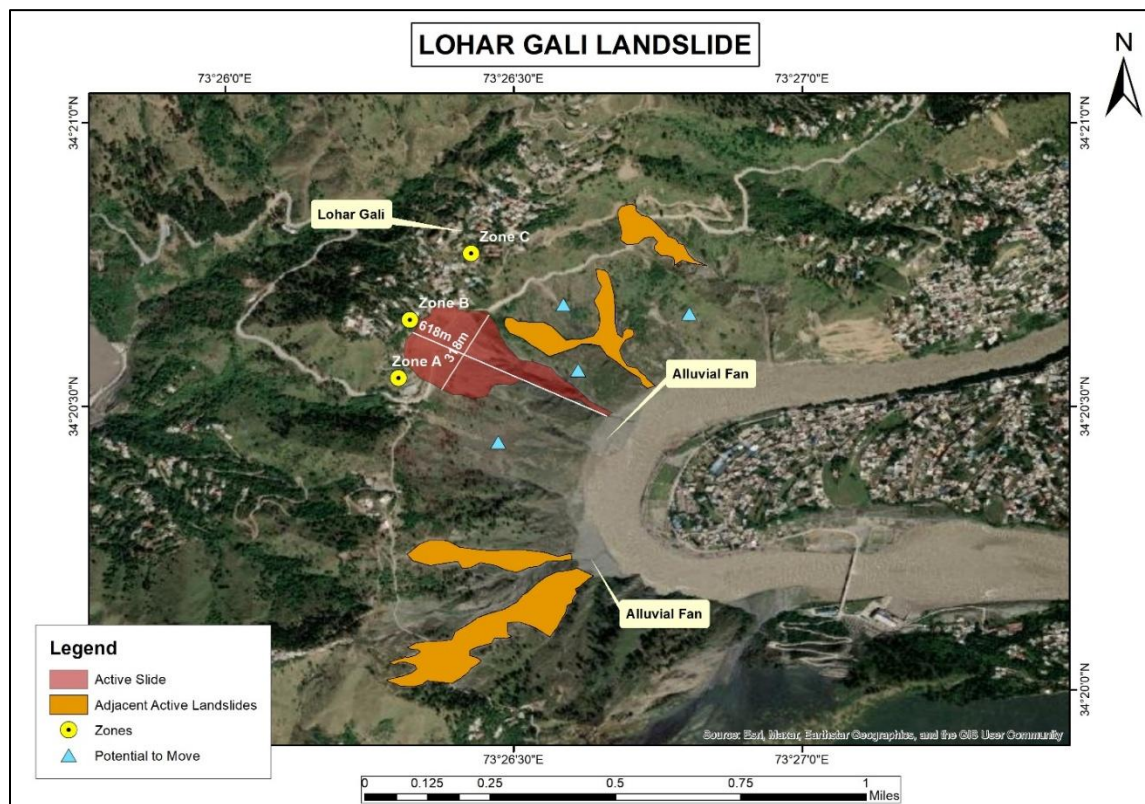


Figure 1: The above map of Lohar Gali Slope failure shows geomorphological features illustrations including the main road structures and flow direction into the Jhelum river below (Source:ArcGIS).

Evaluating landslide risks is crucial in Engineering Geology, particularly along transportation routes. Therefore, a thorough analysis of factors such as slope height and angle, human activities, dynamic loads (e.g., earthquakes), meteorological events (e.g., rainfall or snowmelt and impacts



on river flow and course), and operational activities is essential during the planning and design stages.

Field studies have revealed a persistent movement in the landslide body of up to 3 m at the crown of the slide, accompanied by circular failure characteristics. Additionally, the study shows that the rocks in this area are fragile and prone to fracturing. At depths ranging from 12 to 55 m below the surface, major cracks have been detected with the presence of water. Field studies have shown that human activities at the top of the slide exacerbate the risk of further failure. Additionally, the slip surface has been identified in several sections of the landslide, at depths ranging from 10 to 30 m above which the upper soil layer is shifting.

In this context, the current study has categorized this landslide into three distinct zones. The initial zone (a) extends from the western bank of the Jhelum River to the main highway, characterized by steep terrain and drainage systems that channel materials into the river during periods of heavy rainfall. The second zone, situated above the highway, presents significant hazards, as rapid rock movement and sliding are intensified by the erosion of the road maintenance foundation. The third zone (c) includes Lohar Street, where residential structures are subsiding. Some have already collapsed, while others remain at risk (Figure 2). Contributing to the landslide are sewage, household water, and a drain that accelerates the sliding process.

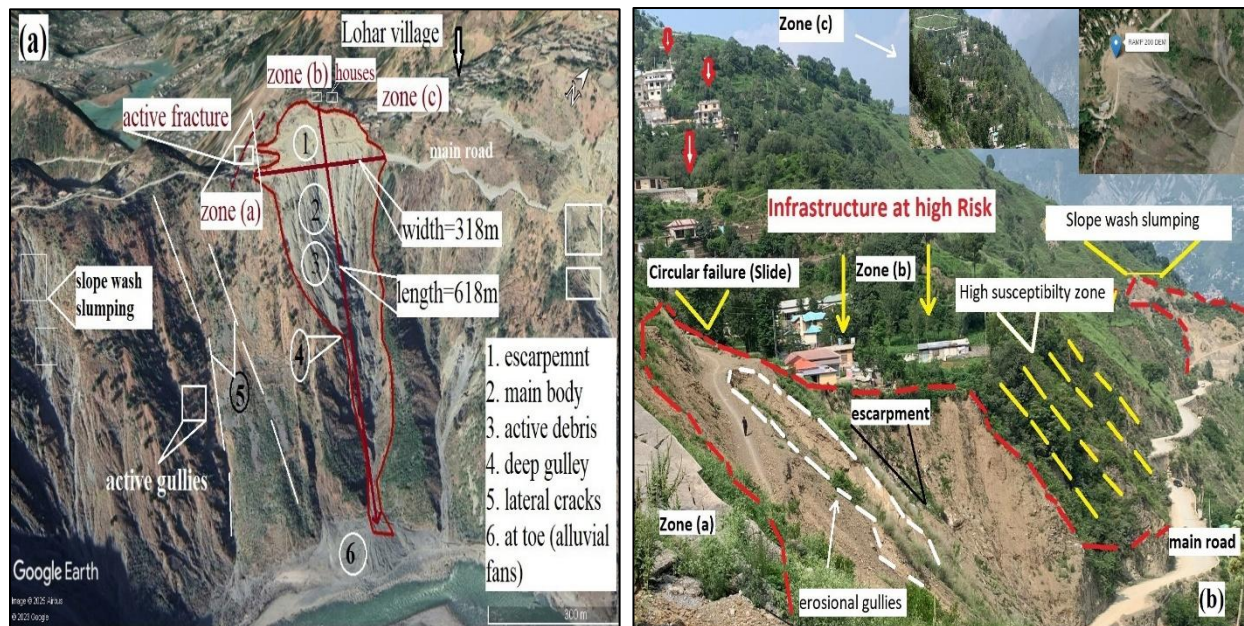


Figure 2: The above Google Earth picture (a) shows the aerial view of western section features of Lohar Gali slope; (b) shows the circular failure steeply dipping strata, escarpment slope adjacent to main highway with striations of sliding over blocks, infrastructure at high risk with risk zonation (a,b,c).



2. Discussion and Conclusion

Studying the Lohar Gali Landslide requires development of data supported engineering geological models (geomorphological, hydrological and environmental and anthropogenic) on which to base pragmatic and cost-effective slope design. In the study area, the strata consist of highly imbricated layers of slates, phyllites, and shales with a steep slope of 60° to 70° . These foliated rocks are more susceptible to climate impacts, particularly during monsoon seasons. The central section of the slide has been deepened and enlarged by parallel gullies that the natural drainage pattern has facilitated. With the help of geotechnical instrumentation, further investigation will be conducted to identify the causes.

The article also suggested instrumentation for monitoring and guiding mitigation of landslides. Geotechnical instrumentation will be crucial for monitoring slope behavior during and after operations. Several recommendations are proposed to address the issue: First, the affected road should be temporarily closed to prevent potential loss of life and property. Second, an alternative route should be identified to allow transportation to continue. The affected population should be evacuated to a safe area. Excavation at the toe should be strictly prohibited, and proper drainage systems should be installed at the crown and other critical areas to manage both surface and groundwater flow. The study conclusions will give engineering geologists, highway engineers, and geomorphology experts important information about Lohar Gali slope failure and efficient landslide risk management. Future research should include geotechnical instruments to monitor ongoing movement, and an Early Warning System should be implemented to provide timely alerts and improve preparedness.

Acknowledgment

I am grateful to IAEG-YEG for providing me with the opportunity to submit an article. Additionally, I would like to express my appreciation to Association for Engineering Geology, Pakistan (AEGP) for selecting me as the Young Engineering Geologist representative from Pakistan.

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