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Major natural hazards in Nepal Himalaya

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Abstract
The Himalayan range was formed by the collision of the Indian plate and the Eurasian plate about 55 million years ago, and this process is still ongoing. This is why the Himalayas are known as the youngest mountain range in the world. The Himalayan chain extends between the vast plains of the Indus and Brahmaputra rivers in the south and the high Tibetan Plateau in the north. From east to west, it is delineated by the eastern and western Himalayan bends. The range is approximately 2400 km long and 200-300 km wide. The ongoing collision continues to shape the Himalayas, with Nepal playing a crucial role as it lies entirely within this range.
The dynamics of this continental collision create remarkably diverse geological conditions within Nepal's narrow width of about 250 km. These conditions, along with significant topographical changes, contribute to various geological hazards, including earthquakes, landslides, floods, soil erosion, and debris flows [3]. Additionally, the high rate of glacier melting due to global warming poses a serious threat to Glacial Lake Outburst Flood (GLOF) hazards. However, the risk level of these hazards varies throughout Nepal.
In this paper, the author investigates significant natural hazard events in Nepal, with a primary focus on geological hazards, and explores their causes and consequences. The study reveals that Nepal is among the most disaster-prone countries globally, experiencing major hazardous events occasionally. Each year, Nepal faces numerous hazardous incidents, resulting in the loss of lives and extensive damage to infrastructure across the country. The research highlights the unpredictability and severity of these events. The findings underscore the importance of understanding the underlying geological factors contributing to these hazards and the critical impact they have on Nepal's communities and development.

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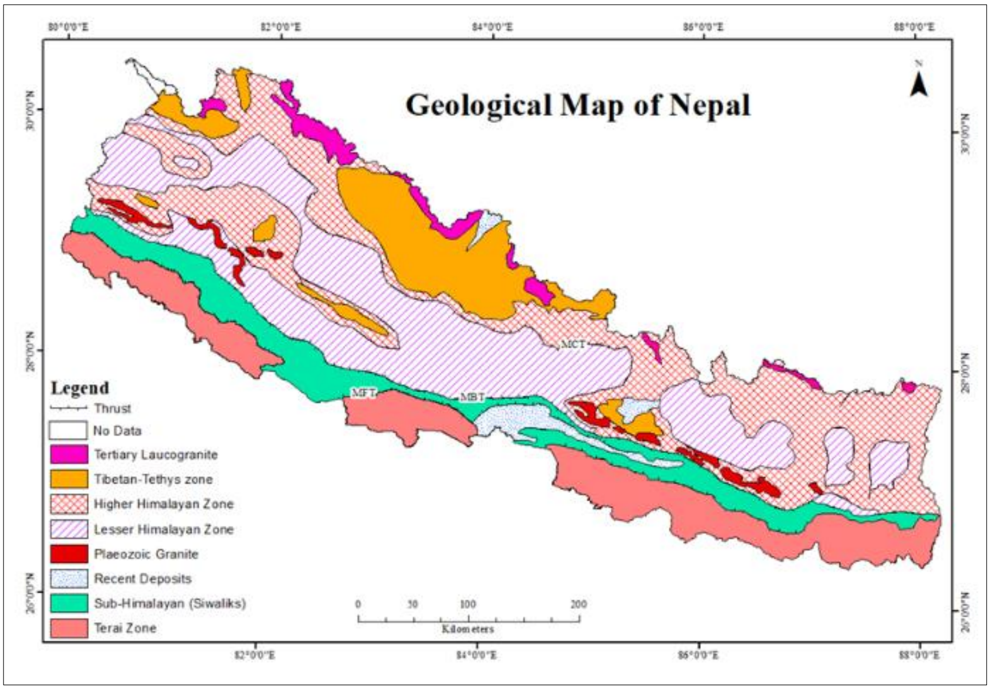
1. Introduction

Nepal Himalaya covers a quite long area extending for about 800 km starting from the Mahakali River in the west and ending at the Tista River in the east [1]. It covers mountain ranges in Nepal, lies in the central section of the Himalayas, and is mainly divided into five morpho-tectonic zones from north to south [1, 2, 4] shown in Figure 1.

1. Tibetan Tethys Zone
2. Higher Himalaya Zone
3. Lesser Himalaya Zone
4. Siwaliks
5. Gangetic Plain (Terai)



Source**:** Kshetri, R. 2023

Fig 1: Geological Division of Nepal Himalaya

Geologically, Tibetan Tethys Zone (rain shadow zone and dry throughout the year), Higher Himalaya Zone (extremely rugged terrain, very steep slope, deeply cut valleys, and permanent snow cover), Lesser Himalaya Zone (rugged and steeper slope, high altitude, cold winter, and warm summer), Siwalik (unconsolidated materials with small hills), and Terai (plain land) from north to south.

2. Major Hazards in Nepal Himalaya

A hazard is defined as a dangerous phenomenon, substance, human activity, or condition that may cause loss of life, loss of livelihoods and services, social and economic disruption, or environmental damage. It is also the probability of the occurrence of a potentially damaging phenomenon within a specific period and given area. When a hazard evolves due to natural processes and phenomena, it is called a natural hazard. Geological hazards are a type of natural hazard arising from or linked to geological processes and phenomena, for example, Earthquake, Tsunamis, Volcanic Eruptions, and Landslides, while Flood disasters are mostly caused by meteorological factors.

In Nepal, weak and adverse geological conditions, combined with extreme hydrometeorological conditions, have triggered hazards such as landslides, erosion, sediment deposition, and floods. Major geological hazards include earthquakes and various types of mass movements, such as landslides, slope failures, and debris flows. While volcanic activities are a type of geological hazard, there is no possibility of such activities occurring in Nepal.

2.1. Earthquake

Nepal lies in one of the most seismically active regions due to the collision between the Eurasian and Indian plates. This collision causes the Indian plate to be thrust beneath the Eurasian plate, with a convergence rate of 45 mm per year in central Nepal. Over the last century, earthquakes with a magnitude of 6.0 or higher on the Richter scale have occurred eight times in Nepal. Records indicate that an earthquake of magnitude 8 or greater can be expected approximately once every eighty years. Research has identified around 92 fault lines in Nepal that are associated with seismic activity [5].

Nepal ranks 11th among the most earthquake-vulnerable countries in the world and holds the first position in terms of total human casualties in urban areas. The Gorkha earthquake, which struck on April 25, 2015, at 11:56 am local time, had a magnitude of 7.8 and was the worst natural disaster to hit Nepal since the 1934 Nepal-Bihar earthquake [6].

This devastating earthquake resulted in thousands of people being left homeless, with entire villages flattened across many districts. The earthquake also caused significant destruction to centuries-old buildings at World Heritage Sites in the Kathmandu Valley, including Kathmandu Durbar Square, Patan Durbar Square shown in Figure 2, Bhaktapur Durbar Square, Changu Narayan Temple, Boudhanath Stupa, and Swayambhunath Stupa. Subsequent aftershocks continued to affect Nepal, with a 6.7 magnitude aftershock on April 26, 2015, and a major 7.3 magnitude aftershock on May 12, 2015. The consequences of these earthquakes resulted in 8,970 fatalities, with 198 people missing and 22,303 seriously injured. A total of 604,930 houses were destroyed completely, and 288,856 houses were partially damaged. The estimated total value of the damages caused by the earthquakes is NPR 706 billion, or approximately US$ 7 billion [7].

***Source*:** www.hinduismtoday.com/magazine/october-november-december-2015/2015-10-special-feature-earthquake-devastates-nepal-s-sacred-sites/

Fig 2: Damaged sacred site in Kathmandu valley after 2015 Earthquake

2.2. Landslide

Landslides are the most frequent and lethal geological hazard in Nepal, often triggered by earthquakes and intense rainfall. Approximately 83 percent of Nepal's terrain is mountainous [1, 3], and the region's rugged topography, complex and fragile geological structure, soft soil cover, high rainfall intensity during the monsoon season, and frequent earthquakes make the hills particularly vulnerable to landslides. The steep gradients of Himalayan rivers and streams significantly contribute to various types of landslides. Each year, especially during the monsoon season, landslides cause considerable damage to life and property. Many hill villages in Nepal are situated on unstable slopes or old landslides, which are periodically reactivated.

***Source*:** English.nepalpress.com/2021/09/05/vehicular-movement-obstructed-as-landsilde-hits-pokhara-baglung-road-section/

Fig 3: landslide obstructs the highway in Nepal

One of the most significant landslides in Nepal's history occurred in Jure village, Sindhupalchowk, on August 2, 2014, at around 2:36 am local time shown in Figure 6. According to local newspapers, this massive, rainfall-induced landslide killed 156 people [8]. The landslide, characterized as a rock avalanche or slope failure, deposited a large volume of debris in the Sunkoshi River, blocking it and creating a potential threat of a lake outburst flood. It took nearly 12 hours for the lake to fill and overflow the debris dam [8]. The dam was eventually released by blasting. A local earthquake of magnitude 3.3 was recorded that day due to the landslide, as reported by the Ministry of Irrigation, Nepal Government.

Figure 3 exhibits the typical landslide that often happens in Nepal, especially in the monsoon season. Recently, on 12th July 2024, two-night buses were swept away into a swollen river by a massive landslide at Simaltal on the Narayangarh-Muglin highway, named Simaltal landslide. The tragic incident happened around 3:30 am and it is believed that around 65 people were killed. So far, 25 bodies have been found the downstream of Narayani River and Bihar India, while some bodies and two buses are still missing. The search for the missing buses and passengers is still ongoing.

2.3. Flood

Nepal is the second highest country at risk of floods in South Asia [9]. Regular flooding, particularly during the monsoon season, results in significant loss of life, property, and livelihoods. Between 1972 and 2011, floods in Nepal caused 3,329 deaths, affected 3.9 million people, and resulted in economic losses of about US$5.8 billion. On average, 300 people die annually due to floods [10]. Significant flood events include the 1993 floods in Central Nepal, the 2008 Koshi embankment breach floods, the 2013 and 2014 floods in the mid and far western regions, and the Melamchi floods of 2021 shown in Figure 4, all of which caused immense loss of life and property and had a devastating impact on development.

Nepal typically experiences heavy rainfall during the monsoon months, making extreme precipitation and flooding common in the southern plains during this season. The monsoon is generally active for about three months across Nepal. Despite this regularity, the 2017 floods surpassed historical records in terms of extent and scale, frightening the entire Terai belt from Jhapa in the east to Kailali in the west simultaneously.

***Source*:** nepalitimes.com/banner/nepal-valley-suffers-quadruple-disaster

Fig 4: Deadliest flooding in Melamchi Bazar Sindhupalchowk in 2021

In early August 2017, monsoon troughs of low pressure developed parallel to the foothills of the Nepal Himalayas, causing heavy downpours across the southern Chure (Siwalik) hills for several days. This relentless rain brought widespread flooding across the region, particularly in perennial rivers such as the Koshi, Mahakali, Narayani, and Karnali. According to the [11], The flood resulted in the deaths of 160 people, with 29 reported missing, and thousands affected. The Ministry of Agriculture and Development estimated that the flooding caused damage to planted crops worth approximately NPR 8.1 billion.

On June 15, 2021, a massive sediment-laden flash flood occurred in the Melamchi River, Nepal, resulting in significant losses and destruction to the settlements. A subsequent flood on July 31, 2021, caused further damage with large debris. The Melamchi events damaged 252 households in Helambu and 287 households in Melamchi municipality, cutting off road access to several settlements. The disaster resulted in 5 human casualties, left 20 people missing, and deposited debris over 10 meters high in Melamchi [12]. A flood hazard report following the disaster suggested that the flood was exacerbated by the outburst of the Pemdan glacial lake (located upstream in the Melamchi catchment), which destroyed the natural dam in the Bhemathan area and eroded the riverbed [13].

2.4. Glacial Lake Outburst Flood (GLOF)

Glacial Lake Outburst Flood (GLOF) is not a new phenomenon in Nepal, but these once-rare events are now exacerbated by climate change, which has led to increased glacial melt in the Higher Himalayan Zone. GLOF typically occurs when large parts of a glacier break off, or when sizeable landslides or avalanches crash into a glacial lake, threatening the stability of the moraines that contain these lakes [14]. These lakes are often impounded on the downstream side by end moraines made up of unconsolidated material, such as sand, clay, and gravel. The instability of this material is compounded by regular freezing and thawing.

When landslides enter the glacial lake, they can cause flood waves that easily erode the unstable end moraines, breaking these barriers and triggering outburst floods with enormous destructive force. GLOFs resemble tsunamis, with floodwaters squeezed into narrow gorges below the lake, creating surge waves of 10-15 meters or higher, which can destroy up to 150 km downstream. Earthquakes can further destabilize the natural end moraines, increasing the risk of a GLOF.

Source**:** neptrek.com/tsho-rolpa-lake-trek-cost-itinerary/

Fig 5: Tsho Rolpa glacial lake in Dolakha district Nepal

So far, 24 GLOF events have been recorded in Nepal [15, 16]. On September 3, 1998, the Tam Pokhari glacial lake outburst caused by an ice avalanche resulted in the loss of human lives and more than NRs 156 million in damages [15]. A 2009 study using remote sensing technology identified a total of 1,466 glacial lakes in Nepal, of which six were classified as potentially dangerous and required further field studies. Detailed studies were undertaken on three highly dangerous lakes: Tsho Rolpa, Imja, and Thulagi. For Tsho Rolpa shown in Figure 5, significant efforts have been made to analyze the end moraine structure, reduce water levels in the lake, and establish early-warning systems for downstream communities at immediate risk.

2.5. Landslide Dam Outburst Flood (LDOF)

Landslide Dammed Outburst Floods (LDOF) occur when heavy rainfall or earthquakes trigger significant landslides, obstructing rivers in mountainous regions. This obstruction creates temporary dams, submerging the upstream area and causing flooding downstream when the dam eventually breaks. An example of this occurred on May 5, 2012, near Machhapuchre Mountain in Kaski District, Nepal. A landslide temporarily blocked the Seti River, leading to a massive flash flood when the blockage gave way. The flood, reaching heights of 30 feet, resulted in the tragic loss of 17 lives, with approximately 50 individuals reported missing. Many of the victims were enjoying picnics near the river at the time [17].

Source**:** English.pardafas.com/jure-landslide-survivors-to-get-compensation-in-cash/

Fig 6: A massive landslide formed temporary dams in the Sunkoshi River in Sindhuplachowk in 2014

Massive landslides called Jure landslides formed the temporary dam in the Sunkoshi River in 2014 shown in Figure 6. The landslide, characterized by typical slope failure with massive rock fragments, sand, and soil, deposited a large volume of debris in the Sunkoshi River, blocking its waterway. It took nearly 12 hours for the lake to fill and overflow the debris dam, creating a potential threat of a lake outburst flood [8]. However, the lake was released by blasting method to reduce the potential risk of LDOF.

2.6. Snow Avalanche

A snow avalanche is the swift movement of snow down a hill or mountainside, often occurring in the Higher Himalayan zone of Nepal between December and April due to heavy snowfall and dynamic loads like earthquakes. In recent years, Nepal has witnessed significant avalanche events:

In 2014, a snowstorm-induced avalanche struck central Nepal in October, claiming the lives of at least 43 individuals from various nationalities [18], including 21 trekkers. The severity of the snowstorms and avalanches around the Annapurna and Dhaulagiri mountains contributed to injuries and fatalities.

On April 25, 2015, a powerful earthquake measuring 7.8 magnitude triggered an avalanche from Pumori into the Everest Base Camp shown in Figure 7. This event resulted in the deaths of at least 23 people and 61 injured [19], making it the deadliest disaster on Mount Everest at the time, surpassing the 2014 avalanche that killed 16 people and most of them were Sherpa guides [19].

Source: eu.usatoday.com/story/news/world/2015/04/26/mountaineers-guides-everest-avalanche/26410705/

Fig 7: Massive snow avalanche plowed through Mount Everest base camp after earthquake in 2015

More recently, on October 12, 2018, an avalanche on Mount Gurja (7,193m) in western Nepal claimed the lives of 9 individuals [20]. Preceded by a heavy snowstorm, the avalanche buried and destroyed their base camp at 3500m. Mount Gurja, situated in the Annapurna region near Dhaulagiri, is known to be particularly avalanche-prone.

3. Conclusion

Indeed, Nepal faces a multitude of geological hazards beyond just avalanches and landslides. Rock falls, rockslides, rock avalanches, soil erosion and deposition, debris flow, and weathering of rocks all contribute to the country's vulnerability to natural disasters. These hazards have caused catastrophic damage, resulting in thousands of fatalities and significant economic losses amounting to billions of dollars.

In response to these challenges, Nepal has relied on financial and technical assistance from international partners. Following major events such as earthquakes, international support has been crucial for providing relief, rehabilitation, and reconstruction efforts. However, Nepal needs to develop comprehensive pre-plans and techniques to mitigate the impact of future hazards.

By studying past hazard events, Nepal can better predict and prepare for future occurrences. This includes investing in infrastructure and systems for early warning, improving land use planning to minimize risk exposure, implementing sustainable environmental practices to reduce erosion and slope instability, and enhancing disaster response and recovery capabilities. Collaborating with international partners and leveraging expertise from various sectors will be vital in building resilience and safeguarding communities against the impacts of geological hazards.

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I would like to acknowledge all the researchers who conducted relevant research in the same study area.

5. Author contribution

The author has the original idea for the paper and took overall responsibility for the study, including data collection and analysis, preparation of figures, and finalization of the manuscript.

6. Conflict of interest

The authors reported no potential conflict of interest.

7. Data availability

The data that support the findings of this study are available from the corresponding author.

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