Engineering Geology of Recent Hydro-climatic Disasters in Nepal

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Abstract: Continuous rainfall starting on September 27, 2024, triggered widespread flooding, inundation, and numerous landslides across Nepal, severely affecting various regions. With 77 out of 222 rainfall monitoring stations reporting over 200 mm of rainfall, several rivers, including the Sapta Koshi, reached dangerous levels, resulting in significant damage. Kathmandu Valley experienced record-breaking rainfall, leading to the flooding of over 1,200 homes and widespread power outages. The disaster also devastated rural districts, with landslides and flash floods severely impacting areas like Dhading, Sindhupalchowk, Koshi Province, and Bagmati Province. Infrastructure, including bridges and highways, was heavily damaged, with 23 highways affected and losses exceeding 2 billion. The disaster caused substantial economic impacts, particularly for rural communities reliant on agriculture. The combination of weak geological formations, poorly planned roads, and inadequate slope stabilization measures contributed to widespread landslides, while rivers like the Bagmati and Trishuli experienced severe erosion. The situation highlights the urgent need for improved disaster risk reduction strategies, including better infrastructure design, urban planning, and early warning systems to mitigate future impacts in flood- and landslide-prone areas of Nepal.

Keywords: ***Heavy Rainfall, Nepal, Landslide, Flood, Infrastructure damage.***

Introduction

Continuous rainfall starting on September 27, 2024, led to widespread flooding, inundation, and numerous landslides of varying scales across the country. According to the Department of Hydrology and Meteorology (DHM), out of 222 rainfall monitoring stations operating nationwide, 77 stations reported heavy rainfall, with amounts exceeding 200 mm on Saturday. Among the hydrological gauging stations installed in various rivers, 23 recorded water levels above the danger mark, while an additional 14 stations reported levels exceeding the warning threshold.

In the Sapta Koshi River, the water flow reached its highest level in 56 years, with a discharge of 643,040 cusecs. Kathmandu Valley also experienced record-breaking rainfall on Friday and Saturday, with DHM identifying Saturday's downpour as one of the highest ever recorded in the valley (Figure 1). The DHM's Tribhuvan International Airport station in Kathmandu recorded 239.7 millimeters of rain in 24 hours, surpassing the previous record of 177 millimeters set in 2002. The entire Kathmandu valley was inundated on 27 and 28 September, submerging numerous houses. The disaster has resulted in loss of life, destruction of homes, and significant damage to infrastructure. In this paper, the number of deaths, damage to properties and infrastructure, and an overall situational analysis of the disaster is reported.

Affected area

The floods and landslides affected multiple regions across Nepal, with Kathmandu Valley and surrounding districts like Dhading, Sindhupalchowk, and Kavrepalanchok being hit particularly hard. Torrential rains caused rivers such as the Bagmati, Bishnumati, and Hanumante to overflow, flooding nearby settlements in Kathmandu and Lalitpur. Areas like Godavari, Imadol, and Lubhu faced severe disruptions, with thousands displaced as homes were submerged and widespread power outages occurred. In Dhading district, places like Jhyaple Khola suffered significant destruction, with landslides burying vehicles and homes.

Koshi and Bagmati provinces, along with other central regions, also reported numerous landslides and flash floods. The districts of Kathmandu, Lalitpur, and Bhaktapur experienced severe impacts, with nearly 77 fatalities in the valley alone. Over 1,200 homes were flooded, while blocked roads disrupted transportation. Bhaktapur was particularly affected by inundation from the Hanumante and Bagmati rivers, leading to significant power outages across the valley. Sindhupalchok district also witnessed deadly landslides that buried residents while they slept, underscoring the widespread nature of the disaster. Despite ongoing rescue efforts, further rainfall forecasts raise concerns about additional damage. Major highways, including the Araniko and BP highways, were blocked, cutting off several regions from essential aid and delaying rescue operations. Continuous rainfall also damaged critical infrastructure, including transmission lines, resulting in long-term power outages.

In Eastern Nepal, Koshi Province suffered from landslides and floods that devastated districts such as Dhankuta, Jhapa, Ilam, and Morang. Over 500 homes were submerged, and landslides obstructed several major highways, hampering rescue efforts. Panchthar and Dhankuta were among the worst-hit areas, where landslides claimed numerous lives, including children. In Pakhribas Municipality of Dhankuta, entire families were buried under debris. Morang and Jhapa districts also faced significant river flooding, displacing hundreds of residents.

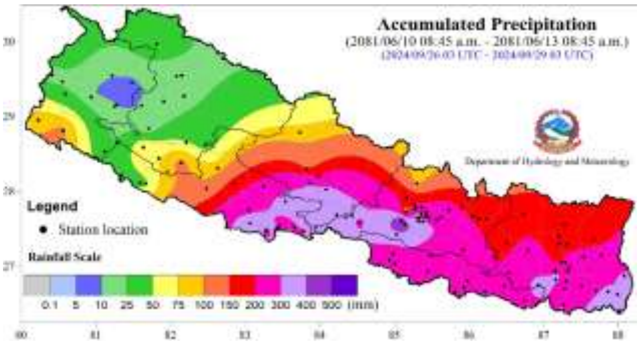

Figure 1, Accumulated Precipitation on September 27-29, 2024 (DHM 2024)

A total of 23 highways across Nepal have been affected, with estimated losses surpassing 2 billion due to roadblocks and damaged bridges. The Bhote Koshi River swept away three concrete bridges—Larcha, Liping, and Ghatte Khola—along the Araniko Highway, which serves as a key route between Nepal and China. Landslides have also blocked several sections of the highway, while water levels in multiple rivers, including the Narayani, Kankai, Kamala, Bagmati, Eastern and Western Rapti, and Babai Chepang, have risen to dangerous levels. In Koshi Province, four bridges were destroyed, including the one over Hewa Khola on the Mechi Highway in Panchthar, and the permanent bridge over Rati Khola connecting Ilam Sandakpur. Additionally, flooding washed away the bridge linking Ramechhap and Sindhuli districts in the Khurkot area.

Economic Impact

The disaster is expected to have a significant economic impact. The destruction of homes, infrastructure, and agricultural land will result in considerable financial losses for both individuals and the government. The cost of rebuilding damaged infrastructure, such as roads and bridges, will be immense. Additionally, disruptions to transportation and agriculture could lead to long-term economic challenges, especially for rural communities that depend heavily on farming as their main source of income (Figure 2).

Engineering geological causes of disaster

The affected regions are dominated by weak, fractured, and weathered rock formations, particularly schists, phyllites, and slates from the Lesser Himalayan Zone. These types of rocks are highly susceptible to failure during intense rainfall, leading to both shallow and deep-seated landslides. The heavy downpour, concentrated over a short period, caused rivers to swell, intensifying erosion along riverbanks and contributing to debris flows. Large quantities of loose sediment were also carried by the rivers, exacerbating downstream flooding. In several areas, inadequate natural drainage systems resulted in waterlogging and slope saturation, further increasing the occurrence of landslides.

Figure 2, Total Economic Loss (NDRRMA 2024)

Poorly planned and designed rural roads in mountainous regions, lacking proper slope stabilization measures, triggered many landslides. Excavations for new road corridors destabilized slopes, leading to additional failures. Settlements built on unstable hillslopes and floodplains increased vulnerability, with construction practices that failed to account for geological conditions or slope mitigation measures, intensifying the landslide risk during the heavy rainfall.

Rivers such as the Trishuli, Roshi, Sunkoshi, Bagmati, and their tributaries experienced severe bank erosion, damaging nearby infrastructure including bridges, roads, and settlements. Saturated debris accumulated during the rainfall was flushed down steep slopes, creating destructive debris flows that covered and damaged large areas with boulders and debris, making them more hazardous than typical landslides. Protective structures such as check dams, retaining walls, and slope stabilization measures were either insufficient or entirely lacking along rural roads and newly excavated areas, worsening the impact of the disaster.

These engineering geological challenges emphasize the urgent need for improved disaster risk reduction strategies, focusing on better infrastructure design, urban planning, and early warning systems in areas prone to floods and landslides in Nepal.

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