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Commentary

Nepal 2015 Earthquake: Uncertainty Prevails in the Himalayan Arc

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At the junction of the Indian and Eurasian tectonic plates, an immense amount of energy builds up as the Indian plate continuously moves under the Eurasian plate. This buildup of energy has given rise to the highest mountains in the world; however, it also makes the Himalayan region seismically hazardous. As a result of this tectonic process, which began between 40 and 50 million years ago, the Himalayas have seen many great earthquakes, and seismic risks persist in many areas along the Himalayan arc, including in Bhutan, India, Nepal and Pakistan. In many parts of the region, seismic events are often accompanied by secondary geological hazards, such as landslides, avalanches and floods. The impacts of the Nepal earthquake on 25 April 2015 and subsequent aftershocks have been devastating, killing over 8,600 people, damaging 780,000 houses, and triggering numerous secondary geohazards. The International Centre for Integrated Mountain Development (ICIMOD) is providing technical support and scientific information to the Government of Nepal to meet challenges in the aftermath of the earthquake. This disaster highlights the importance of cooperation and coordination among countries in the Himalayan region to improve understanding of seismic risks in the region and prepare for earthquakes and their subsequent impacts in the future.

The Himalayas, which stretch 2,500 km from Pakistan to Myanmar, partially or fully covering Bhutan, China, India and Nepal, are home to the world's tallest mountain ranges. However, the Himalayas did not always exist. Forty to 50 million years ago, the Indian subcontinent collided with Asia, giving rise to the Himalayas. The same tectonic forces that resulted in the formation of the Himalayas are also responsible for the region's seismic activity.

The Himalayan region is known for seismic hazards and high risks prevail all the time (Bilham *et al.,* 2001). Each year, the Indian plate moves 12 to 18 mm under the Tibetan Plateau, building up an enormous amount of energy along the Himalayan Arc. This energy contributes to the annual growth of the region's highest peaks, including Mount Everest, which is estimated to grow about 6 cm each year. However, this energy is periodically released through ruptures in the Earth's surface that can result in devastating earthquakes.

The history of large Himalayan earthquakes stretches back for centuries. A large earthquake presumably occurred in 1505 ($8.9 \approx M_w$) in an area west of Kathmandu that stretches to Himachal Pradesh in India. Other large earthquakes in eastern Nepal along the Indian border of Bihar occurred in 1255 ($8.4 \approx M_w$) and 1934 ($8.2 \approx M_w$) (see Sapkota *et al.,* 2013). More recently another large earthquake ($8.6 \approx M_w$) occurred in Assam, India in 1950. The area ruptured during the recent 2015 earthquake in Nepal also saw similar ruptures in 1833 and 1866. In 2005, an earthquake in Pakistan measuring 7.6 M_w with an epicenter near Muzaffarabad killed more than 85,000 people. Greater details on the history of earthquakes in India and Himalaya can be found in Bilham (2004).

The 7.8 M_w Nepal earthquake on 25 April 2015 and subsequent aftershocks have had devastating impacts, with 14 districts of Nepal particularly hard hit. More than 8,600 people have been killed, among which over 55% were female, and over 780,000 houses were completely damaged. The 2015 Nepal earthquake also resulted in casualties in Bangladesh, India and the Tibet Autonomous Region of China. Up

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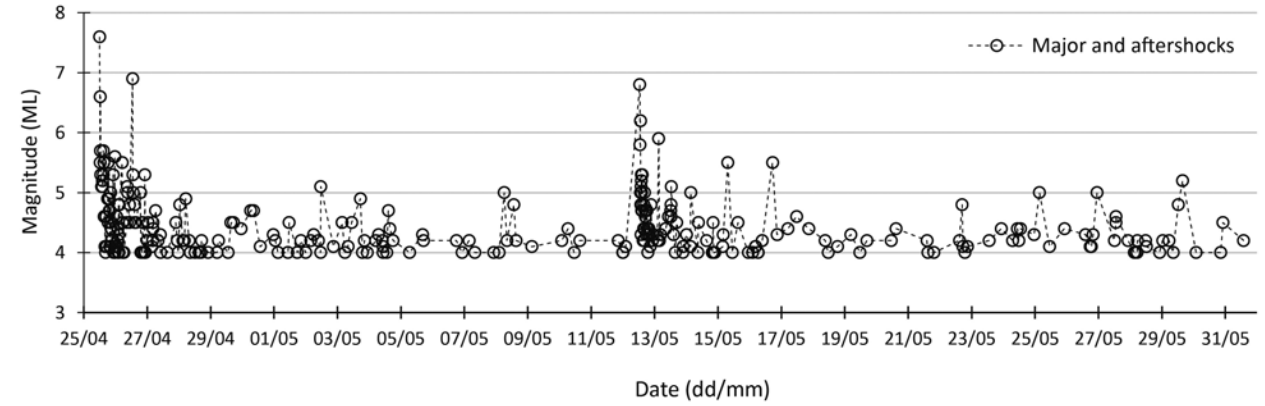
to 31 May, more than 290 aftershocks were felt following the main earthquake on 25 April, and aftershocks are still occurring at the time of writing this article (Fig. 1).

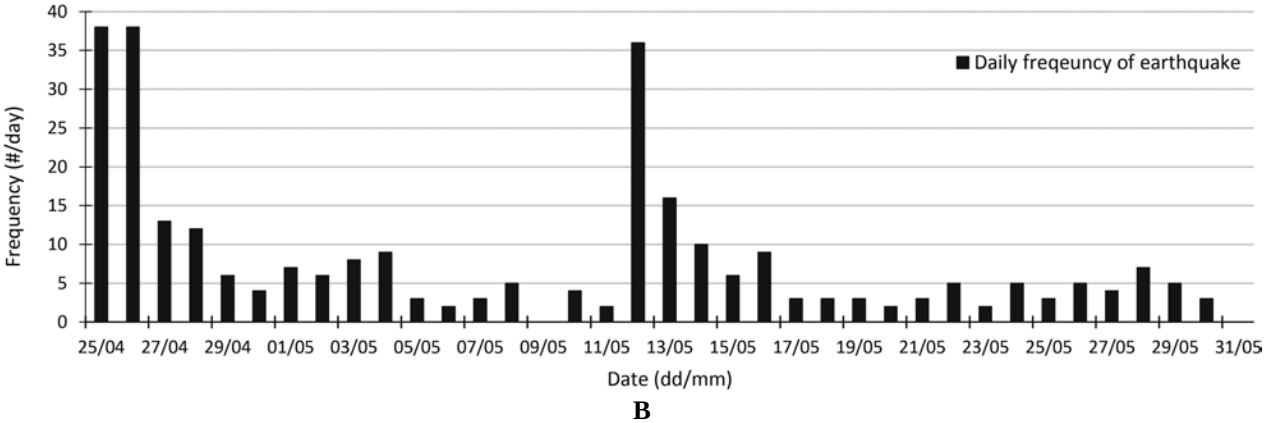
In addition to the immediate impacts on people's lives and damage to infrastructure and homes, the earthquake also triggered numerous geological hazards, including landslides and avalanches that have further devastated the country. Even one month after the first tremor, risks of secondary geohazards remain a major concern, and the attention of a large number of scientists within Nepal and beyond has been drawn to the potential secondary risks that might arise in the near future.

A rapid assessment of geohazards in the aftermath of the 25 April earthquake was conducted for the Government of Nepal by a Geohazards Task force at the ICIMOD in collaboration with an international team of scientists. The assessment found that as many as 3,000 landslides have occurred in the steep mountains and hills throughout the earthquake-affected area. In collaboration with the international team of scientists, ICIMOD has also conducted an assessment of glacial lakes in the Himalayas. This study found little additional risk of earthquake-induced flood outbursts for the potentially dangerous glacial lakes in the earthquake-impacted area, but recommended regular monitoring of the lakes and their surrounding environment.

In addition, ICIMOD collaborated with the international team of scientists to evaluate the hazards that contributed to a post-earthquake disaster in the Langtang Valley. The initial report by the team



A



B

Fig. 1: Earthquakes measuring more than 4 Richter Local Magnitude (ML) earthquake and aftershocks (A) and number of earthquakes and aftershocks per day (B) from 25 April 2015 till 31 May 2015. Source: National Seismological Centre, Department of Mines and Geology, Nepal (*the magnitude of earthquakes and aftershocks shown in Fig. 1 differ from the magnitudes mentioned in the text, as the figure is based on data from the National Seismological Centre of Nepal, which is reported in Local Magnitude, whereas the values in the text are magnitude based on USGS measurements*)

suggests that the 25 April earthquake caused part of a hanging glacier on Langtang Lirung and Langtang II mountains above the valley to become unhinged and collide into the mountain below, prompting an avalanche of snow, ice and rock material that covered the majority of the upper valley's largest village (Fig. 2). Additional analysis suggests that a destructive pressure wave accompanied the avalanche in certain parts of the valley. As a result, the valley's eight highest villages were damaged or completely destroyed and numerous lives were lost. The team is now working to assess the current conditions in the valley and to identify potential future hazards.

As aftershocks continue and the monsoon season begins, the possibility of more geohazards remains. The ICIMOD Geohazards Taskforce will continue to analyse, monitor and assess potential secondary hazards in earthquake-affected areas, including landslide-dammed rivers, future mass movements (landslides/debris flows) and glacial lake moraine dam failures.

The ICIMOD Geohazards Taskforce is coordinating with a broad international team that includes the governments of India (Indian Space Research Organization – ISRO), Pakistan (Space and Upper Atmosphere Research Commission – SUPARCO), China (Chinese Academy of Sciences), and Nepal, as well as other bodies like the National Aerospace and Space Administration (NASA), the University of Arizona, United States Agency for International Development (USAID), Utrecht University, Esri, Japan Aerospace Exploration Agency (JAXA), Digital Globe, International Charter on Space and Major Disasters, and the US Geological Survey (USGS). The maps and reports developed by the Taskforce are available on ICIMOD's website: www.icimod.org/nepalearthquake2015.

A taskforce formed by the Government of Nepal consisting of various ministries and departments and experts from ICIMOD has been tasked with assessing landslide risk to human settlements in view of the impending monsoon rains. The team will visit six high priority districts – Dolakha, Rasuwa, Nuwakot, Dhading, Sindhupalchowk and Gorkha. It is expected that the first comprehensive assessment will be completed by 5 June 2015, after which a report will be submitted to the Government of Nepal.

In consultation with the Government of Nepal, ICIMOD is also exploring ways to support reconstruction and rehabilitation efforts in the areas where it has worked or is working through its projects and pilots. Efforts to rebuild must adopt an integrated approach that looks holistically at rebuilding stronger houses and public infrastructure, restoring water supply and sanitation, supporting livelihoods and considering factors related to natural resource management, gender, governance and knowledge management. As efforts shift from relief to the reconstruction of people's homes and livelihoods and cultural heritage sites, preparedness for potential

A **B**

Fig. 2: (A) The 25 April 2015 earthquake-triggered avalanche and landslide in the Langtang valley covered the majority of the upper valley's largest village. (B) The deposit of the avalanche and landslide (background) as well as structures destroyed by a subsequent pressure blast (foreground). ***Photo credit: David Breashears/Glacier Works***

secondary risks must still remain a priority. As ICIMOD continues to utilize its core strengths in response to the earthquake, it is also leveraging its network and resources related to private sector and corporate social responsibility activities to support earthquake recovery efforts, including linking its partners in affected areas with organizations and private companies who could support rebuilding and reconstruction.

Uncertainty still remains in the minds of many people living in the Himalayan region, and especially those in Nepal. As science has not yet developed reliable earthquake prediction or early warning systems, people living in the seismically volatile Himalayas must continue to live with the constant threat of earthquakes, as they have done for centuries.

While there will continue to be some degree of seismic uncertainty until related scientific advances are made, there are steps that can be taken to better prepare communities in the Himalayan region for earthquakes and their related hazards. There is a need for scientists and academia in the Himalayan region to cooperate and coordinate efforts, both to reduce risks prior to earthquake, as well as to effectively support disaster response, as is highlighted by the collaboration between ICIMOD and numerous institutions around the world to identify and assess potential geohazards in the aftermath of the 2015 Nepal earthquake.

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