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The Melamchi flood disaster

Cascading hazard and the need for multihazard risk management

PREPARED BY*

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KEY MESSAGES

The Melamchi disaster of 15 June and the following days cannot be attributed to a single factor. It was the result of multiple anthropogenic and climatic factors and processes that occurred at various locations along the Melamchi River.

The Melamchi-Indrawati watershed receives high precipitation, which increases, along with altitude, towards the north. This disaster was initiated by intense precipitation in the upstream areas, which triggered cascading hazards along the river corridors, causing loss of life and extreme devastation to settlements, markets, roads and bridges, and local livelihoods.

Cascading hazards are becoming more common in Nepal and in the Hindu Kush Himalaya, demanding a more holistic approach in hazard assessment and risk management.

The flood damage impacted different population groups differently, with many families displaced from their homes. Subsistence farming-based families have incurred a permanent loss of highly valuable agriculture and farm land, which has impacted their livelihoods and subsequent well-being. Many such vulnerable families might be pushed to seek alternative livelihoods away from home, and potential outmigration for labour or permanent settlement elsewhere cannot be ruled out in the future.

Early warning via informal risk communication from upstream communities helped to reduce loss of lives and livelihoods in downstream communities. There is a need to establish early warning systems in the watershed with strong involvement from upstream and downstream communities, supported by local and national government entities.

This study was based mainly on remote sensing information, and a rapid field assessment in the downstream part of the watershed should be augmented by aerial observation and detailed field investigation, particularly in the upstream high-altitude area of the watershed. This will provide deeper understanding in building the resilience of the region in the future.

1. Nepal, a natural hazard hotspot

Nepal, which is located in the central part of one of the youngest and most active mountain ranges – the Himalaya – is formed by the ongoing convergence of two active tectonic plates. It is a country prone to various natural hazards such as landslides, avalanches, debris flow, flash floods, glacial lake outburst floods, earthquakes and thunderstorms because of its fragile and complex geological setting, physical diversity and climatic variation. The existence of weak, shattered rock and thick soil/debris cover on steep and rugged topography coupled with climatic variability, the monsoons and frequently occurring earthquakes makes the country vulnerable to natural hazards. In addition, recent unplanned and unmanaged anthropogenic interventions on unstable terrain has increased the scale of hazards. However, for the identification and proper development of safe places for urbanization, it is essential to understand the interactions between geological and geomorphological settings and climatic variability. The DesInventar and Building Information Platform Against Disaster (BIPAD) portals, which record past disasters, show that disaster events in Nepal have increased in recent decades and that landslides, debris flows, thunderstorms and floods are the frequently occurring major disasters. Among the major disasters in the past decade are the Seti Flood in 2012, the Jure landslide dam in 2014, the Gorkha earthquake in 2015, glacial lake outburst floods (in Bhote Koshi in 2016 and Barun Khola in 2017), the Terai floods in 2017, the tornado in the Bara-Parsa district in 2019 and the landslides and debris flow in Sindhupalchok in 2020 (Gurung et al. 2015, Yagi et al. 2021., Geest 2018, Miyake et al. 2017, Liu et al. 2020, Byers et al. 2019 & Shrestha et al. 2019). These disasters have taken a significant toll in terms of both lives lost and property damage.

This year, too, at the onset of the monsoons (around 10 June 2021), several high flow and debris flow events were reported from around the country. The first reported was from Mustang where, on 14 June, a debris flow occurred in the Lupra valley just north of Jomsom. Slightly further southeast in Manang, multiple small rivers carrying high flow caused damage to many villages and damaged some roads disrupting access. On 16 June, the Melamchi Bazaar was hit by a heavy flash flood from two tributaries – the Melamchi and Indrawati rivers – which resulted in 5 deaths and 20 missing persons along with heavy damage to the Melamchi water supply project while cutting off road access to several villages. Furthermore, on 18 June, it was reported that a landslide had blocked the Tama Koshi River leading to the formation of a lake on the Chinese side of the border (Rongxer), roughly 8 kilometres (km) from it, which threatened downstream infrastructure and communities. Considering the magnitude of the disaster and the loss of lives and property, the Disaster Task Force of the International Centre for Integrated Mountain Development (ICIMOD) carried out a detailed study of the event by analysing all available information, which was supplemented by rapid field inspection. The following sections present the assessment of the event and preliminary findings.

2. What triggered the Melamchi disaster?

The Melamchi disaster cannot be attributed to a single factor. Our analysis suggests that the disaster was a result of multiple factors and processes that occurred at various locations along the Melamchi river. Figure 1 provides an overview of the various processes contributing to the disaster: i. weather conditions, ii. processes in the high altitude glacial environment, iii. processes at the Bremthang old landslide site, iv. formation of a new landslide at Melamchigaon, river damming and outburst flood, and v. riverbank erosion and debris deposition. These hazards, both alone and in combination with others, amplified the scale of the disaster in downstream areas. These processes are described in detail in the following sections.

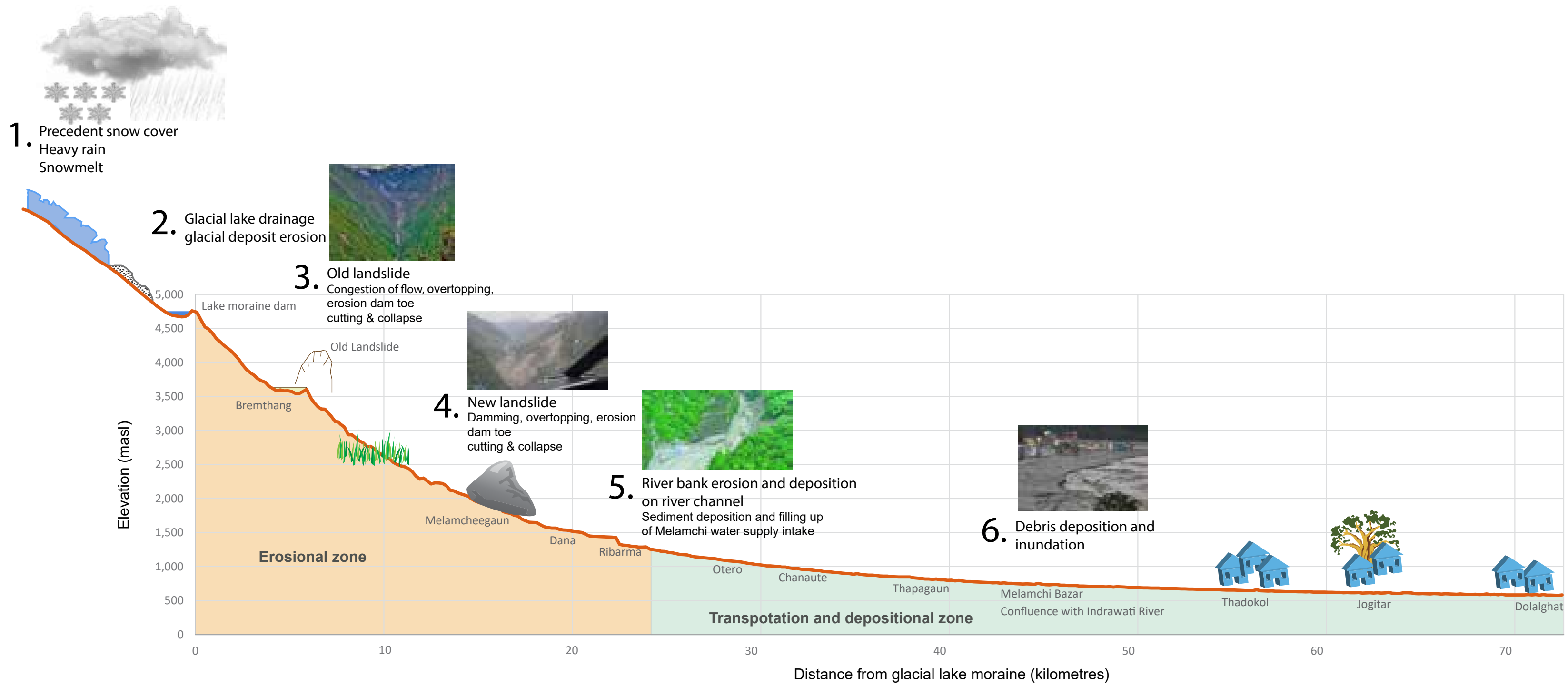

Figure 1: Longitudinal profile of the Melamchi-Indrawati River showing various processes leading to the disaster.

2.1. WEATHER CONDITION

Both the Melamchi and Indrawati basins started receiving rainfall from 9 June as recorded in the automatic weather station of the Department of Hydrology and Meteorology (DHM) in Sermathang, at an elevation of 2625 metres above sea level (masl). While the highest hourly precipitation on 10 June was 22 millimetres (mm), by 11 June, it had increased to 37 mm per hour. On 14 and 15 June, some rainfall was recorded at around a maximum of 10 mm per hour (Figure 2). On 11 June, Semathang recorded more than 100 mm of daily rainfall. During the 6-day interval, the station had, therefore, received more than 200 mm of rainfall.

According to the DHM report on pre-monsoon rainfall monitoring, the daily accumulated rainfall from March to May was 129% above normal, which shows that the watershed had experienced significant precedent precipitation.

Along the Indrawati-Melamchi river corridor, the annual precipitation increases with elevation, the Sermathang station receiving the highest amount of rainfall at approximately 4000 mm annually.

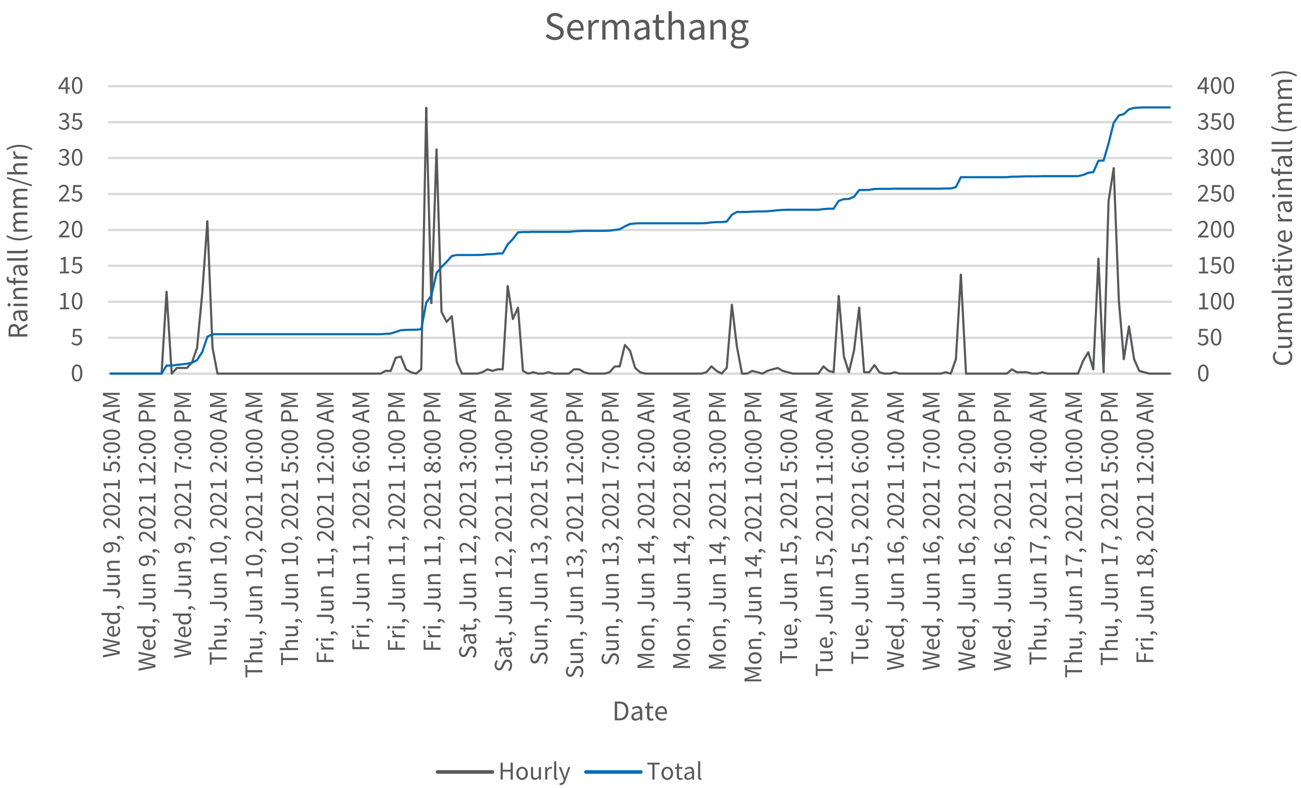

Figure 2: Hourly rainfall recorded by the DHM weather station at Sermathang (2625 masl).

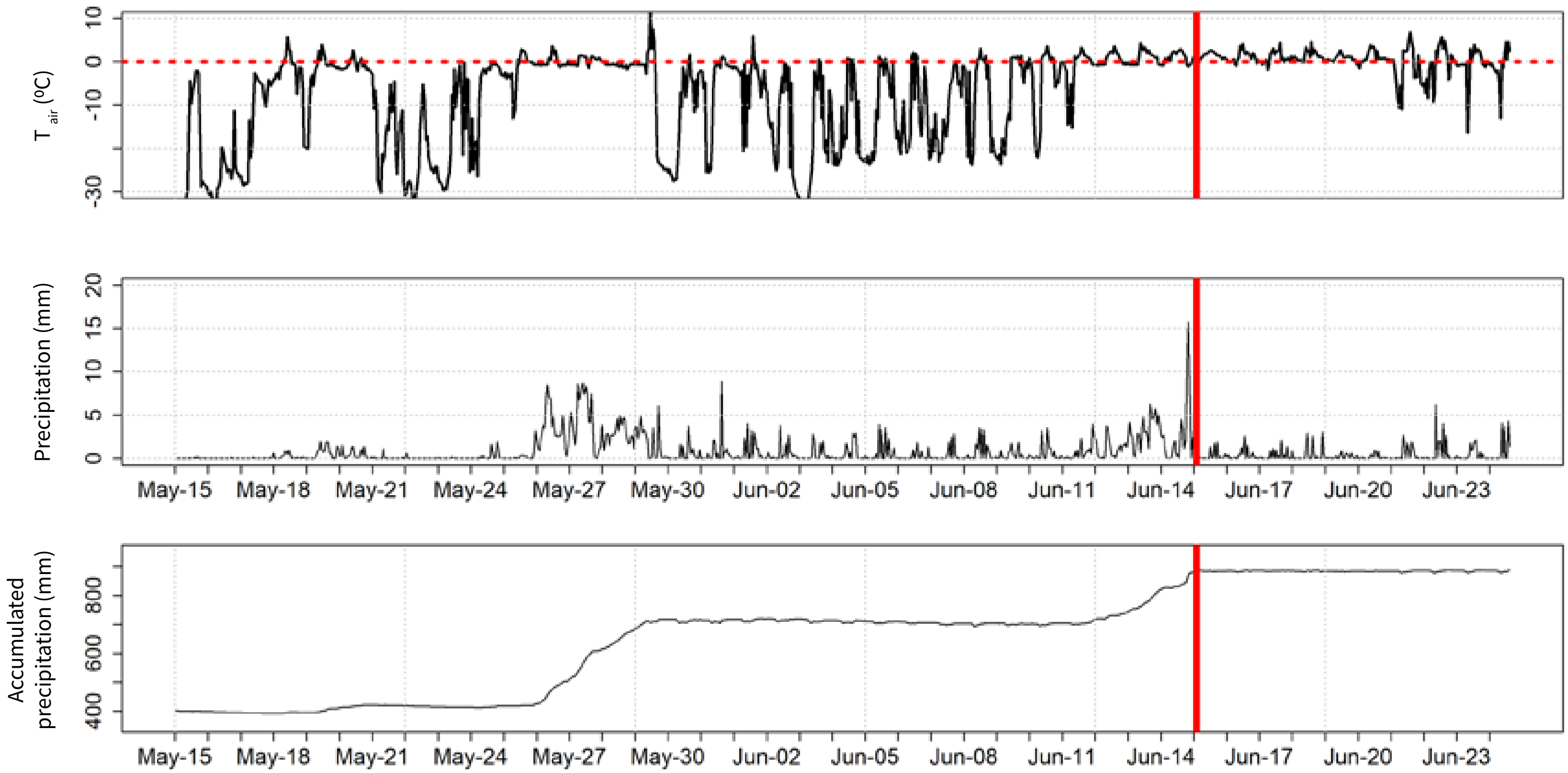

Figure 3: Climate data from the automatic weather station (AWS) in the upper part of the Melamchi watershed at an elevation of 4962 masl. The vertical red line shows the time where most of the known mass movements must have happened according to local sources.

The automatic weather station (AWS) operated by ICIMOD at Ganja La in the upper Yangri Khola shows that just 4 days before the occurrence of the most significant mass flow events, air temperature had risen significantly suggesting a transition to heavy snow melt (Figure 3). At lower elevations, the transition to heavy snow melt likely happened a few days earlier. This coincided with the onset of significant precipitation from 26 May and, then again, just a few days before the disaster event under reference. Some of this precipitation may have happened as rain-on-snow (ROS) which can further exacerbate flood inception.

The Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrievals for GPM (IMERG) also indicates that a large amount of rainfall occurred in the upper catchments from 11 June onwards.

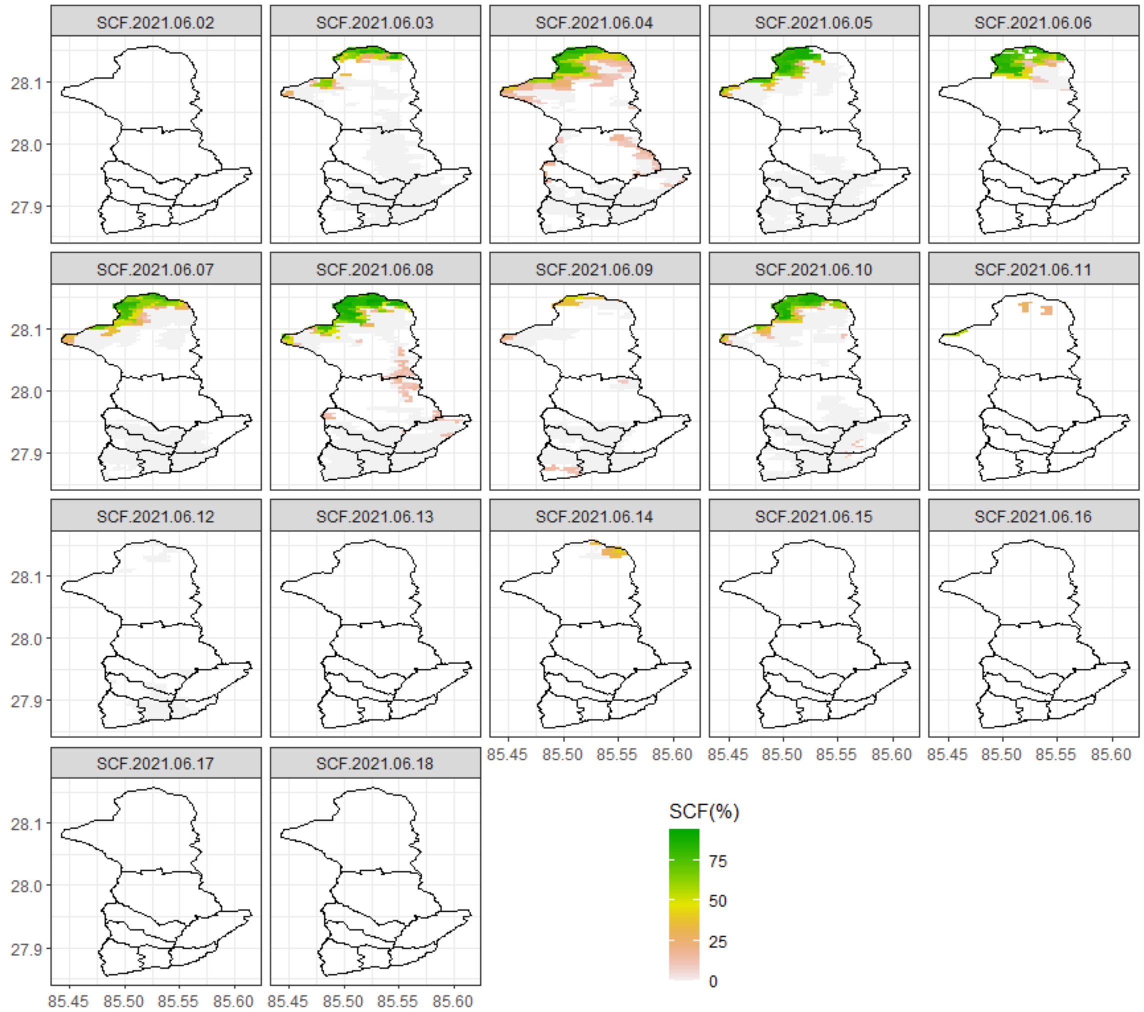

Figure 4: Snow cover change in the Melamchi watershed during the onset of the monsoon. Here, SCF stands for snow cover fraction (Developed by Amrit Thapa, ICIMOD).

2.2. SNOWMELT AND EROSION OF GLACIAL DEPOSIT

Both pre-monsoon precipitation events and the two cyclones, Yaas and Taukte, resulted in significant amounts of snow in the headwater areas of the Melamchi watershed. Analysis of radar images shows that the snow cover had significantly decreased at higher elevations with the commencement of the monsoon in the area (Figure 4). As indicated in the previous section, rapid snow melt and high precipitation resulted in the erosion of glacial deposits in the headwaters of Pemdang Khola, Yangri Khola and Larche Khola. It is estimated that glacial deposit erosion occurred over an area of approximately 70,000 m^2 in the headwaters of Pemdang Khola. Figure 5 shows the large amount of moraines deposited along the Pendang valley. A comparison of pre- and post-event images (i.e., 12 May 2021 images vs. 23 June 2021 images) highlights the disintegration of large moraine deposits on the northern side of the lake. This breakoff of moraine could be due to the high flow from upstream and heavy rainfall as there is no evidence of landslides on the side hillslope and lake or waterlogged features in the upstream area whereas, further downstream, along the moraine deposits, toe cutting and side erosion are clearly visible.

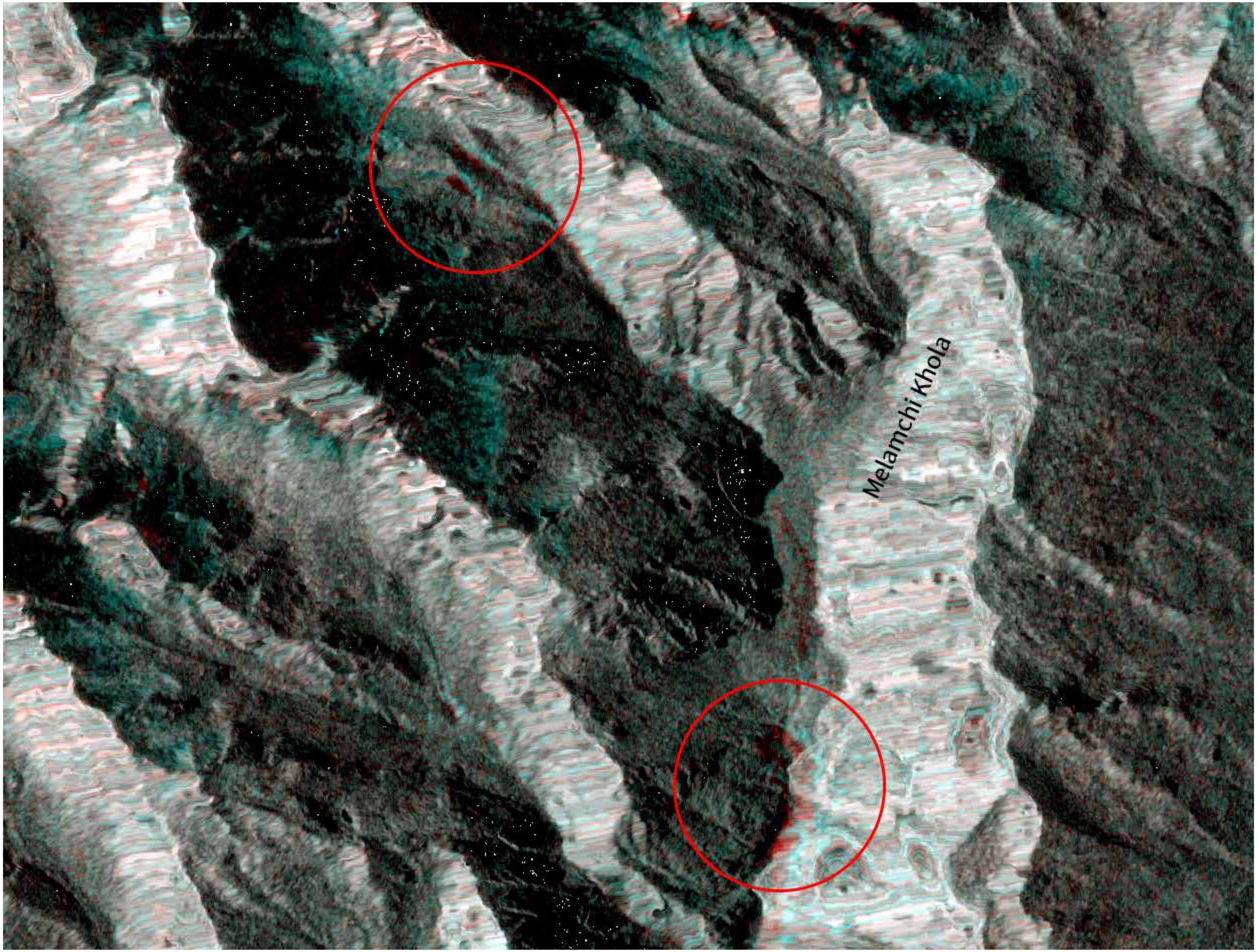

Figure 5: Analysis based on pre-(12 June 2021) and post-(24 June 2021) event images. Sentinel – 1 images capture the end-moraine dam collapse and moraine disintegration in the headwater area of Pemdang Khola.

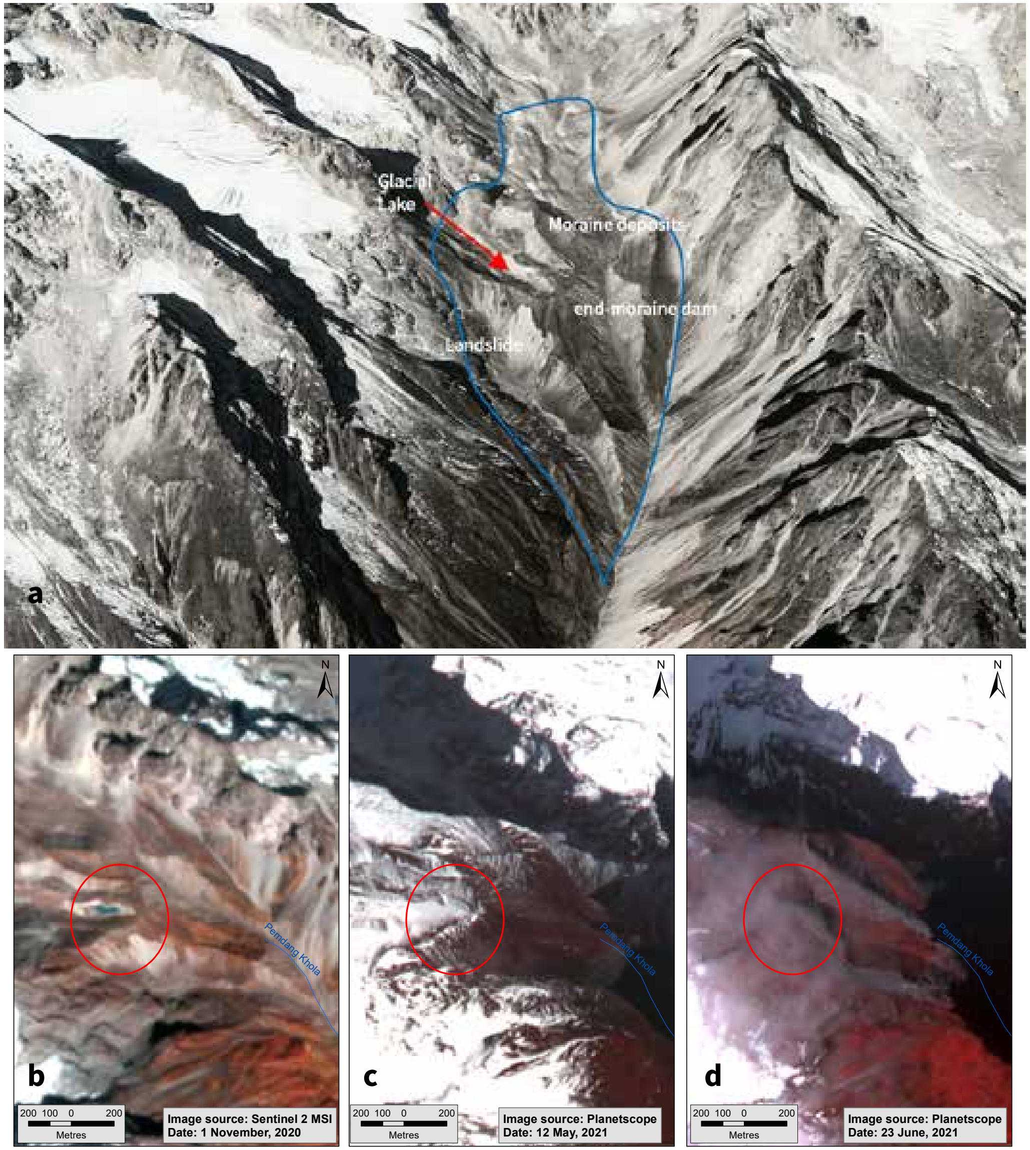

Figure 6: a. 3D view of headwater area of Pemdang Khola showing the glacial lake and moraine deposits along the valley. (Background images from Google Earth; Image date: 15 December 2017); b. – d. Sequential satellite images showing disappearing glacial lake and collapse of end moraine dam.

2.3. GLACIAL LAKE OUTBURST

The Sentinel-2 satellite image dated 1 November 2020 shows a small glacial lake, 2761 m^2 in size, in the headwaters of Pemdang Khola (Figure 6). The lake was situated at an elevation of 4770 masl and had been retained by an end moraine. The height of the end moraine dam (from its toe) was more than 200 metres (m) and a large landslide/sediment movement is clearly visible on the outer slope, including toe cutting and erosion along the overflow path of the lake.

The pre-event image (12 May 2021; Figure 6c) shows that the surface of the lake water is covered by snow and is partly frozen. After the event, as evident from the image of 23 June 2021, the lake is no longer visible, and instead, a v-shaped channel on the end moraine can be clearly seen along with evidence of the washout of a large volume of end moraine deposit along the flow path (Figure 6d). This clearly indicates the breaching of the lake. The breach width is around 40–50 m. As the upstream area is hazy and not clearly visible on the images, the breach mechanism is unknown. The possible main mechanism is heavy rainfall, which could have triggered a debris flow from the upstream area that could have caused the lake water to overtop the dam and erode and breach it. Another possible mechanism is the erosion of the dam due to heavy rainfall and overflow from the lake. An understanding of the detailed breach mechanisms would only be possible through good quality high-resolution images and further field work.

A similar process likely occurred in the headwaters of Yangri Khola as similar environment exists in that area (Figure 7).

Figure 7: The upstream of Yangri Khola in 2018. On the left, the recently deglacierised para-glacial terrain is visible. It was the source of one of the debris flows in June 2021, predominantly from the source visible as bright debris in the centre of the image. On the right, the old moraines slightly downstream are visible with the plateau formed by the old glacier tongue. This same plateau is present in Pemdang Khola as well where the initial flood accumulated and then drained rapidly.

2.4. LANDSLIDE AND RIVER DAMMING

The old landslide dam at Bremthang is located 5.8 km downstream of the glacial lake and 1.8 km downstream of the confluence of Pemdang Khola and Melamchi Khola. The landslide dam is about 950 m long and 900 m wide. Old satellite images indicate that debris flows have occurred in this stretch in the past too as seen by a large fan deposit and a number of talus deposits beside the Pemdang Khola, which are marked in Figure 8.

The water and debris mixed flow originating from the headwaters of Pemdang Khola and Melamchi Khola then filled the 1 km wide plain behind the Bremthang landslide dam. When the flow reached the crest of the landslide dam, it led to congestion within the existing river outlet.

The straight cut-off between the light grey (sediment erosion) and red (vegetation) colour on the image from 23 June 2021 at the crest of the old landslide dam indicates the blockage of flow while a similar light grey coloured linear feature after the cut-off shows the discharge from the dam, overflow, and erosion along the dam (Figure 9c). The rapid flow through the high slope dam eroded the dam crest and resulted in the toe cutting of the dam. This erosion, toe cutting, and collapse of the dam toe was possibly also aided by seepage from the dam (old landslide deposit), which is also visible in the photo shared on social media (Figure 8). Further downstream, a number of bank erosions and cuttings can be seen, which played a role in intensifying the impact of the flood.

Figure 8: (on the left) Photo-showing the outer slope of the Bremthang landslide dam and the area downstream (**Source:** social media). On the right is a Google Earth image (dated 15 December 2017) that shows the morphological features of the river valley at the confluence of Melamchi Khola and Pemdang Khola, about 4 km downstream of the lake area. The brown dash line shows the old Bremthang landslide dam; the yellow dash line shows the fan deposits; the blue dotted line shows the talus deposits; and the light grey patches along either side of the valley are active landslides/rock fall and valley erosions.

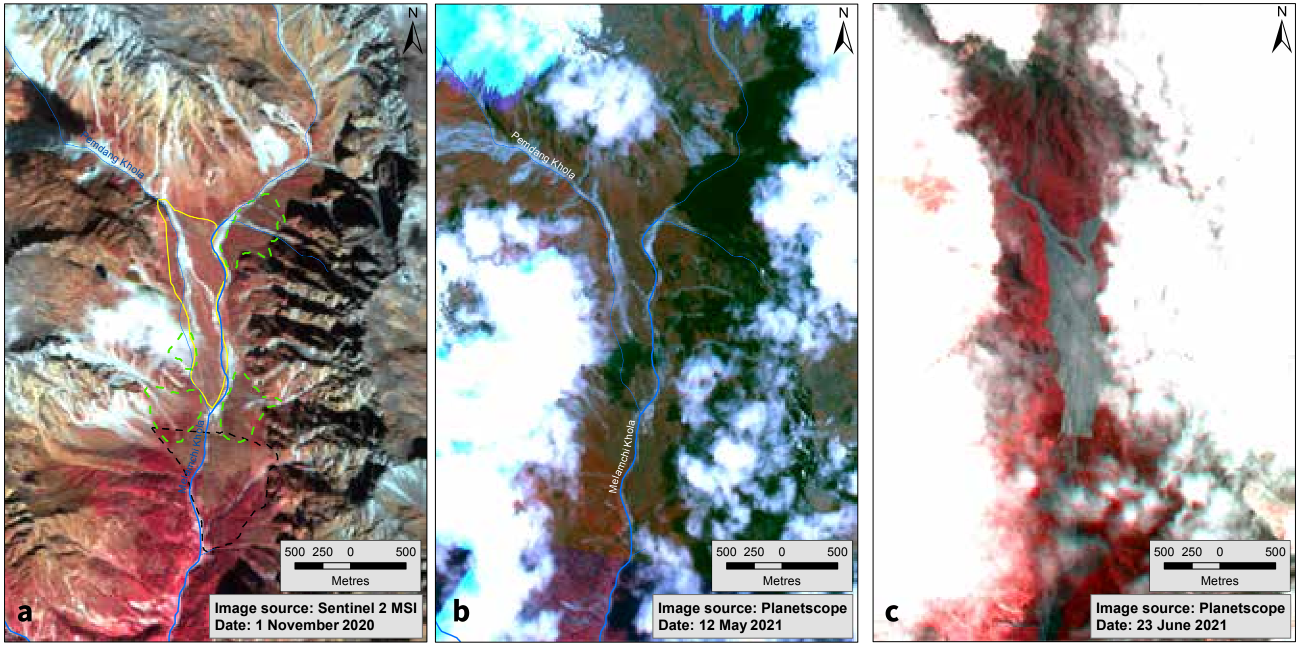

Figure 9: Satellite images showing the erosion on the riverbed and overtopping the old landslide dam area in Bremthang: a. 1 Novenber 2020; b. 12 May 2021; and c. 23 June 2021

2.5. NEW LANDSLIDE

A new landslide had occurred at 28°01'15.948"N and 85°31'57.040"E on the slope to the east of Malamchigaon on the left bank of the Melamchi Khola. The satellite images, field photographs and river flow direction indicate that the landslide had occurred due to riverbank erosion and hillslope toe cutting as a result of the high river flow on the colluvial deposit of an old landslide (Figures 10 and 11). The high-speed debris flow through the narrow river valley had cut the riverbank and toe of the hillslope creating a stress on the colluvial deposit in the hillslope so that it slumped and slid into the river channel blocking the river flow.

The new landslide is 450 m wide in the middle and 550 m wide at the bottom. It is about 450 m in length. It covers a total area of 0.18 square kilometres (km^2) including the crown and the deposited area. A total of approximately 670,000 m^3 of debris, which is estimated based on the empirical volume-area scaling equation (Larsen et al. 2010; Jaboyedoff et al. 2020), sliding down from a 2400 m altitude to about a 2000 m altitude would have blocked the river flow. This blockage would have got filled up with debris flowing from the upstream area. Eventually, the river would have overflowed the landslide by eroding and cutting the damming material and breached out, causing the catastrophic flood that resulted in major damage in the downstream areas.

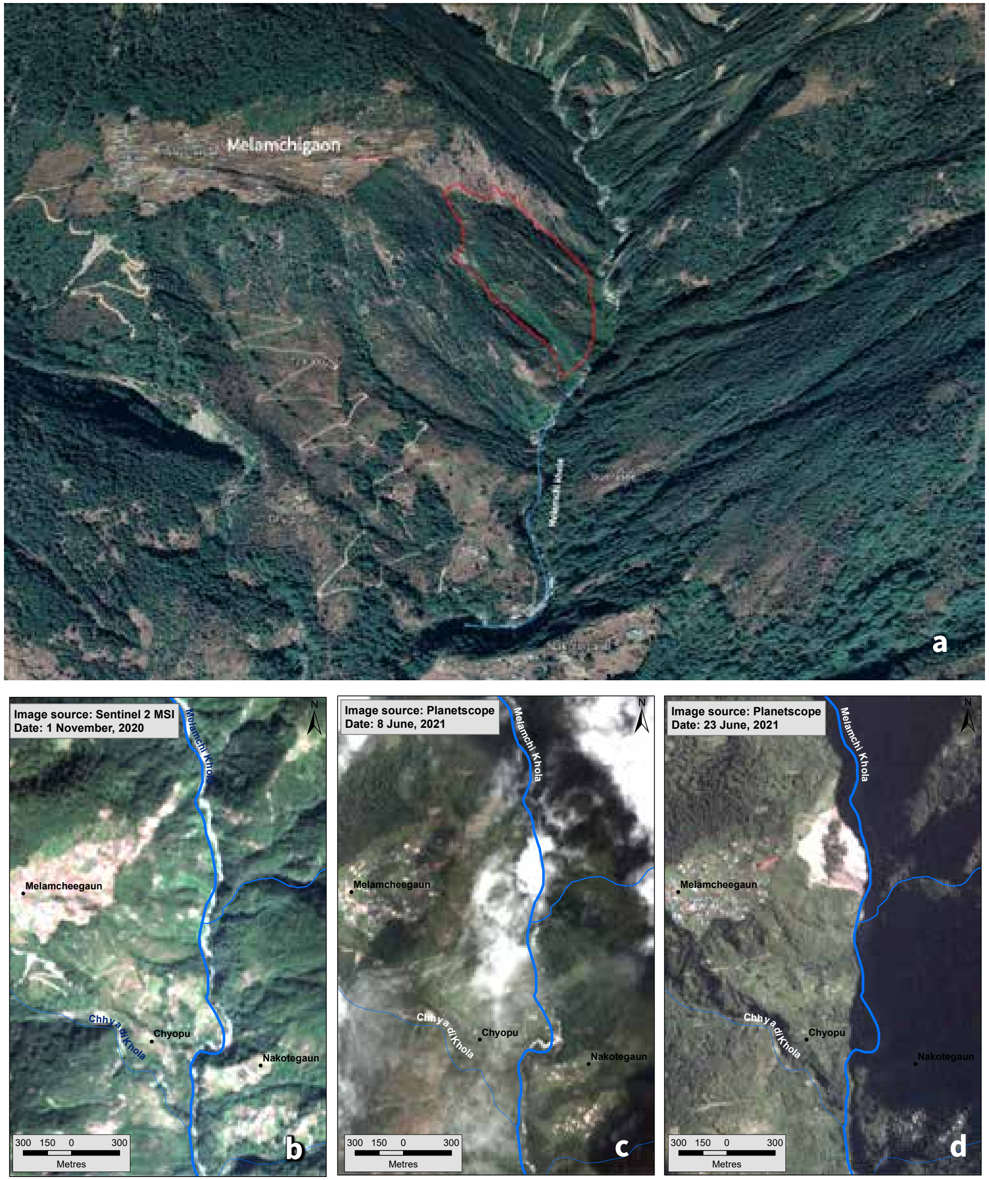

Figure 10: a. 3D view of the landslide area at Melamchigaon as seen from a Google Earth image dated 28 November 2020. Satellite images of the same area on b. 1 November 2020; c. 8 June 2021; and d. 23 June 2021.

2.6. RIVERBANK EROSION AND DEBRIS DEPOSITION

Figure 11: Photograph of the landslide dam taken from a helicopter **(Source:** social media).

Figure 12: A still image from a video shared by Dorze Ghale on Facebook on 25 June 2021 showing the erosional area viewed downstream from Bremthang.

The Melamchi watershed has its origins in the glaciated terrain of Jugal Himal and flows through a typically narrow, V-shaped, rocky, and steep terrain. The river valley consists of numerous alluvial terraces and recent and old landslide deposits along the valley. The stretches after Bremthang and a few kilometres below the new landslide at Melamchigaon can be considered a youthful stage of the river, which has a high potential to erode riverbed material and side banks. The high-speed flow of water hyper-concentrated with debris (glacial deposits in the headwaters of Pemdang Khola and fan, talus, and lake deposits in the Bremthang area) likely eroded the channel and riverbank throughout the stretches, causing numerous riverbank collapses and landslides (Figure 11). The deposition of these sediments commenced a few kilometres below Nakotegaun where the river becomes a slightly gentle and wider channel. A massive amount of sediment deposition can be observed further downstream as the river gradient decreases and the channel becomes wider.

The size of the sediment fills in the river valley is higher upstream of the Melamchi Bazaar. Moreover, the proportion of coarse and larger sized boulder deposition is higher above the Malamchi Bazaar whereas the deposition of finer sediment such as sand and silt including gravel- and pebble-sized sediment is more downstream, which is an area that is more unstable (Figure 13).

The material deposited along the river stretch from near Ribarma village to Haldebesi was estimated by comparing a post-event satellite image from Planetscope with a 5 m resolution ALOS digital elevation model (DEM). The analysis showed that the width of the deposition ranges from 20 m to 385 m with an average width of 163 m covering an area of 6.5 km^2. The volume of the deposit from Ribarma village to Haldebesi near Dolalghat was estimated at 1.3 x 10^7 m. This volume of sediment is enough to fill the area of Kathmandu city within the Ring Road, an area of 43 km^2, up to a height of 0.3 m.

Figure 13: Sediment deposition in the a. upstream part about 1 km upstream from Chanaute Bazaar and b. downstream part (Melamchi Bazaar) of the watershed.

2.7. POSSIBLE EARTHQUAKE IMPACT

While it would not be possible to attribute the recent calamitous event, with any degree of certainty, to slope instability caused by the 2015 earthquake, there are many indications that this was the case. Recent studies have shown that landslides have increased in frequency in the region since the earthquake (Kincey et al. 2021; Rosser et al. 2021). Strong monsoons in the recent past have further exacerbated the situation. In the Melamchi River, a number of landslides (upstream of Melamchigaon) started at a fissure that had appeared after the earthquake. But research on the relationship between seismic hazards and long-term moraine stability is scarce and, in the case of Melamchi, moraine failures are probably largely driven by water saturation.

However, it is likely that moraines and hill slopes in the region are generally disturbed and structurally weak after the 2015 Gorkha earthquake. Sindhupalchok district, within which the Melamchi-Indrawati watershed is located, was one of the worst affected and many landslides had occurred there due to the earthquake (Shrestha et al. 2016).

3. Composite/cascading hazards

The foregoing descriptions make it clear that the disaster across the Melamchi River up to the confluence of the Indrawati was caused by either the simultaneous occurrence of multiple hazards or one hazard triggering the others. The initiation of the disaster event was possibly triggered by high-intensity rainfall on the previous days. Of special note is the precipitation that started on 9 June. It saturated the soils across the hill slopes, the incessant rainfall triggering landslides until the major disaster event of 15 June.

Upstream of Pemdang Khola, a string of factors relying on different time scales seems to have contributed to the flood. In this region, para-glacial terrain increases rapidly as glacier ice recedes, which makes increased amounts of mobile sediment available for mass flow events. Also in the upper tributaries of Melamchi, moraines remaining from the last glacial maximum (LGM) have combined with deposited sediments from glacial melt to form plateaus where debris and water can accumulate before draining rapidly. This was what happened in the case of Pemdang Khola, where the plateau was additionally closed off by an old landslide deposit. The outburst of a small glacial lake might have provided an additional boost to this process.

When it spilled over the old landslide at Bremthang, the debris-mixed water would have caused erosion on the outer slope of the landslide while remobilizing additional material. The debris-laden water with high erosive capacity caused toe cutting at various locations. One major outcome of this was the massive landslide at Melamchigaon. This landslide, in turn, caused river blocking and an outburst flood. The discharge data from the DHM at Nakote station indicates that the flow decreased for 45 minutes at first before suddenly increasing. This suggests landslide blockage and sudden release. Hence, the role of the earthquake in weakening the slopes cannot be discounted.

The nature of the disaster thus suggests cascading hazards which amplified the magnitude of the disaster. It would have been of a lesser degree had it been caused by a single hazard. In the Hindu Kush Himalaya (HKH) region, such escalation of cascading hazards to cascading disasters is a common phenomenon.

4. Risk aspect

4.1. EXPOSURE AND IMPACT

The floods adversely impacted large swathes of areas, including human settlements, agricultural land, river-based livelihoods and critical infrastructure such as roads, bridges, hydropower plants and electric poles. This unprecedented flood event carried with it large-scale debris from upstream which were later deposited in downstream areas, indeed, as far away as Dolalghat which is approximately 54 km away from Melamchigaon (the site of the new landside). The images in Figure 14 show debris deposition in the Melamchi Bazaar area.

According to the initial report of the National Disaster Risk Reducation and Management Authority (NDRRMA), 5 people have been confirmed dead, 20 people reported missing and 6 injured during the floods. The discussions with the Chairpersons of the Melamchi and Helambu municipalities suggest that this initial estimate would have to be revised over time. Considering the scale of the destruction unleashed by the floods, it is likely that quick action by the Municipal Office together with district security agencies contributed to reducing loss of human life. However, the persistent floods over 3-4 days have resulted in 337 fully damaged houses while displacing 525 families as per the initial NDRRMA reports. The floods also destroyed many public infrastructure installations including 13 suspension bridges, 7 motorable bridges and numerous road stretches in a number of locations above the Melamchi bazaar. Among the public investments completely destroyed by floods in the Malamchi bazaar were the

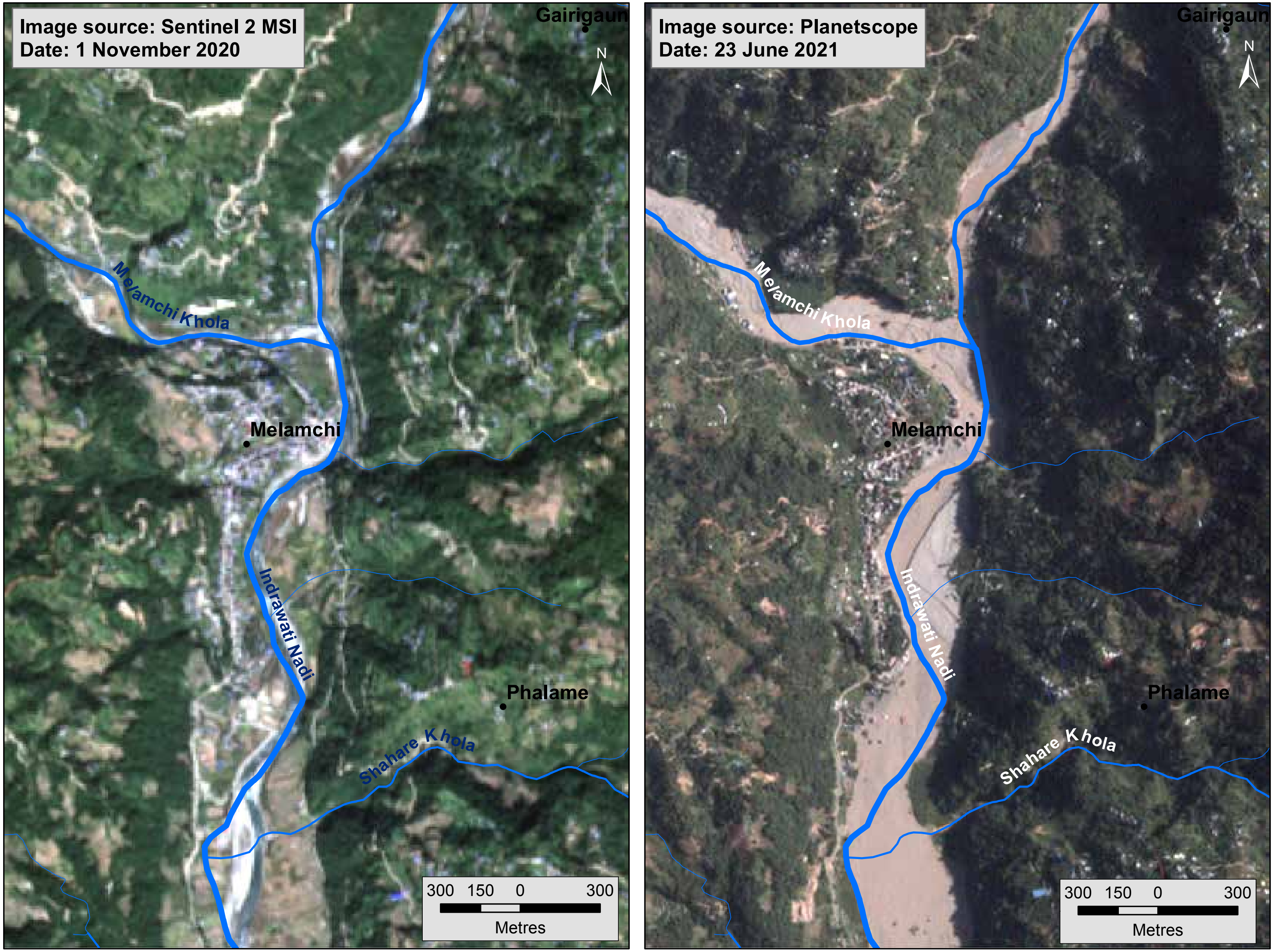

Figure 14: Debris deposition as seen from satellite images taken before (left) and after the event (right).

Green City park, the bus stand and the waste processing centre. The impacts due to loss of life and productive assets as well as damage caused to infrastructure will be felt over a long period of time. Indeed, some wards of both Melamchi and Helambu municipalities are physically disconnected from the outside world due to the washing out of bridges and roads. Other places are virtually disconnected due to disrupted telecommunications, including internet and the power supply.

People's livelihoods too have been significantly affected by the flood. It has fully destroyed 259 enterprises in the Melamchi Municipality, including a hydropower plant and trout farms (based on a presentation made by the Municipality on 2 July 2021). It has also caused significant damage to market centres such as Chanaute Bazaar and Melamchi Bazaar, the impact of which requires further analysis. Most importantly, the flood has turned productive 'khet' (plots of cultivated land) to riverbanks. The Melamchi Municipality alone has lost some 3500 ropani (one ropani equals 508.74 m^2) of khet land, which served as a lifeline for subsistence crop-based farmers.

The impact of the flood damage to the Melamchi Drinking Water Project will be felt as far away as Kathmandu. This project had just commenced delivering water to households in Kathmandu after a long delay. However, due to the massive damage to its intake sites, the water supply can again be expected to be disrupted for a long period of time.

4.2. VULNERABILITY

The flood damage impacted different population groups differently. Overall, the upstream communities were much more vulnerable than the downstream communities. The downstream communities benefited from the early warning received through informal communication from upstream communities in that it played an important role in reducing loss of life. Discussions with the upstream and downstream communities indicated that, before the large floods on the evening of the 15 June, people from the Helambu area called downstream communities, including those in the Melamchi area, about the extreme rainfall, floods and landslide dams in Melamchigaon. This made swift action possible by local agencies and communities to evacuate people from riverside settlements such as the Chanaute Bazaar and Melamchi Bazaar areas before the floods hit. The absence of human casualties in the Melamchi Municipality can be attributed to this. Similarly, a higher risk was borne by communities settled near the river in comparison with the others because of their close proximity to the disaster area. These communities have lost multiple sources of livelihoods such as small shops and agricultural land. Within these communities, families that have lost their only homes and agricultural land face a daunting challenge in managing basic needs such as food, shelter and clothing in the future.

Riparian communities such as fishing communities also face a higher level of vulnerability due to their dependence on the river for their livelihoods. The changing river morphology raises questions regarding their ability to continue with their traditional livelihood option. Apart from the fishing community, Helambu was also known for its trout farming enterprise. It was a vibrant and evolving enterprise sector with 12 farms along the Melamchi River. These farms were of varying capacity with one farm running a guest house with accommodation for up to 50 persons and a self-sufficient agricultural farm. It is difficult to estimate the losses borne by the farm without sufficient information on the investment and insurance coverage. However, as expressed by one trout farm entrepreneur, the practice of risk spreading through insurance is rare in the area, making them very vulnerable to losses such as the above.

Floods also destroyed many hectares of khet land that were highly productive and favourable to growing rice. Subsistence farming-based families have in fact incurred a (permanent) loss of highly valuable khet land as well as the harvest of rice which was planted in Spring this year. This constitutes a significant economic loss raising questions regarding the food and nutritional security of such families. Many such vulnerable families might be pushed to seek alternative livelihoods away from home in the future.

Lastly, children have also been placed in a vulnerable position as regards education with school buildings in a precarious condition as this is bound to disrupt their education in the coming days.

5. Lessons learnt and way forward

The analysis of the cause of the disaster presented in this report is largely dependent on satellite and other remotely collected information and data. There is a strong need, therefore, to validate the analysis by field-based observations.

Discussions with the locals of Helambu and representatives from various affected municipalities indicated that early warning via informal risk communication from upstream communities helped to reduce loss of life in downstream communities. A major factor in making this possible was the timing of the floods, which happened in the evening when it was still light. Should the floods have occurred in the night, the outcomes might have been very different. This shows the importance of having an early warning system that is not entirely dependent on voluntary risk communication from upstream communities. As the risks of future floods remain high, there is an urgent need to work on establishing early warning mechanisms without delay. Lessons on successful informal risk communication, which can be elicited from anecdotes shared by local representatives, shows that a systematically operated community-based early warning system is the one that best fits the needs of communities at risk from such flood disasters.

In recent years, there have been significant advancements in model-based prediction and early warning systems. ICIMOD has implemented one such system, the High Impact Weather Assessment Toolkit (HIWAT), to facilitate probabilistic forecasting and assessment of hazards associated with high impact weather. The system has been customized to capture flash floods in smaller streams with a lead time of 54 hours and visualize the discharge information for individual stream segments over the forecast period. A review of the model predictions in Melamchi, Yangri and Larke rivers showed that HIWAT would have been able to predict the floods in all three rivers two days prior to the event. Lessons drawn from this disaster event show that a rigorous validation of model result accuracy and the development of dissemination mechanisms at the local level can give significant lead time to prepare for floods.

Support for either livelihood recovery or alternative livelihoods for families that have lost all their productive assets (land, livestock, etc.) is another important factor to be considered in the medium term. Preparing for disasters of this nature is a herculean task. However, looking at the frequency of such events in the HKH region and in the Sindhupalchowk district in particular, it is imperative to start planning for disaster risk reduction. An area worth looking at is risk-spreading mechanisms such as insurance coverage of investments and productive assets. Climate-resilient development planning is another area that needs to be considered in preparing for future disasters.

The nature of floods in the mountainous region of the HKH has been changing in the recent years. In February 2021, a massive rockslide just below the Ronti peak melted ice and led to flash floods killing more than 200 people in the Chamoli district of the Indian state of Uttarakhand while causing severe damage to physical infrastructure, including hydropower. A similar disaster happened in 2012 in the Seti River of Pokhara. In fact, there are many similarities between the Chamoli and Seti disasters. The Seti River flood was also caused by ice and rock avalanches on the southern flank of the Annapurna mountain, which caused massive flash floods in the downstream areas. Similarly, in the Uttarakhand flood of 2013, torrential rains caused a chain of events, including landslides and floods and the Chorabari lake outburst and debris flow, which killed over 6000 people and damaged roads, buildings and infrastructure. These changes and extreme disaster events that have been observed in recent years are examples of cascading hazards leading to cascading disasters. In cascading-type hazards, one hazard can trigger another hazard with the cumulative impact much greater than that of a single hazard. The floods in Melamchi, Chamoli, Seti and Uttarakhand can be described as disasters amplified by cascading hazards. Although it is possible to some extent to predict annual floods some days in advance, there is no mechanism to predict cascading hazards in mountainous areas. Unlike events caused by a single hazard such as annual floods, cascading hazards are likely to occur at intervals of several years but the nature of the damage caused is far greater. Considering this, integrated risk assessment is a must. It involves understanding the river morphology, mapping and monitoring hazards, and modelling critical natural processes.

Infrastructure in the mountainous region of the HKH is not designed for such complex disasters. Therefore, readiness before the disaster strikes constitutes a practical approach. It is time that we engaged in a serious discussion of the process mechanism of cascading hazards in the region and invested the necessary resources not only to better understand such events but to better prepare for them in order to prevent the unnecessary loss of human lives and property.

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The International Centre for Integrated Mountain Development (ICIMOD), is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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