**Section A** The fields in this section are mandatory.

**Institution:** Durham University

**Unit of Assessment:** 14 Geography and Environmental Studies

**Title of case study:** Building resilience to earthquake and landslide hazard in Nepal

**Period when the underpinning research was undertaken:** Between 2011 and 2020

**Details of staff conducting the underpinning research from the submitting unit:**

| **Names:** | **Roles (e.g. job title):** | **Periods employed by submitting HEI:** |
|---|---|---|
| Professor Nick Rosser | Professor of Physical Geography | October 2002 to present |
| Professor Alex Densmore | Professor of Physical Geography | November 2006 to present |
| Dr Katie Oven | Postdoctoral Research Associate | November 2009 to August 2019 |
| Dr David Milledge | Postdoctoral Research Associate | September 2009 to July 2017 |
| Dr Tom Robinson | Postdoctoral Research Associate | August 2015 to July 2019 |
| Dr Mark Kincey | Postdoctoral Research Associate | October 2015 to present |
| Dr Jack Williams | Postdoctoral Research Associate | May 2017 to September 2018 |
| Dr Zuzanna Swirad | Postdoctoral Research Associate | July 2019 to January 2020 |

**Period when the claimed impact occurred:** Between April 2015 and July 2020

**Is this case study continued from a case study submitted in 2014?** N

**Section B**

## 1. Summary of the impact

Earthquakes and their associated secondary hazards, such as landslides, are a major and recurring threat to lives and infrastructure in mountainous countries like Nepal. Durham University research on earthquake and landslide hazard in Nepal has informed the humanitarian response to the devastating 2015 Gorkha earthquake, which affected more than 3.5 million people, as well as preparedness efforts for the next major earthquake. The research has produced the only comprehensive maps of landslides that occurred during and after the earthquake through the 2020 monsoon season, and these maps have underpinned nationwide geohazard assessment and relocation efforts by the Government of Nepal in the 14 worst-affected districts. An innovative ensemble of earthquake scenarios prepared by Durham has been utilised by the UN, the Government of Nepal, and major international NGOs to underpin the national earthquake Emergency Response Preparedness Plan, which guides the response of the entire UN Humanitarian Country Team in Nepal to the next major earthquake. This integration of science and humanitarian planning is unique among UN-led disaster preparedness efforts.

## 2. Underpinning research

Research at Durham University has shown how to improve resilience to large earthquakes in Nepal by focusing on two inter-related themes: quantification of the hazard from earthquake-triggered and post-earthquake landslides, and the development of earthquake scenarios for humanitarian contingency planning. We detail these themes and their major outcomes below.

1. Quantification of earthquake-triggered landslide hazard

Durham research since the early 2000s provided the first comprehensive, national-scale picture of landslide hazard in Nepal, demonstrating the costs of pervasive landsliding and indicating the close relationship between monsoon rainfall and landslide losses (reference **R1**). A parallel strand of research has explored the hazard of landslides triggered by recent large continental earthquakes. That work has shown how earthquake-triggered landsliding is both widespread and persistent, complicating humanitarian response and recovery efforts, but also showed that patterns of landsliding from those events can be used to define simple rules to reduce exposure to landslide hazard (**R2**). These research strands were brought together in the aftermath of the 25 April 2015 Gorkha earthquake in Nepal. Durham researchers, in collaboration with the British Geological Survey, produced a preliminary landslide map to support the humanitarian response (**R3**). To understand the evolution of landslide hazard after the earthquake, Durham was subsequently funded by the Foreign, Commonwealth, and Development Office (FCDO) to produce the only comprehensive maps of landslides that occurred during and after the earthquake, through the 2020 monsoon season, across the 14 worst-affected districts. Durham researchers collaborated

with the National Society for Earthquake Technology, a Nepali NGO, to generate these maps. That research has shown that landslide hazard has evolved in space and time but has not yet diminished, as previously-failed material has been extensively remobilised by monsoon-triggered landslides and debris flows over the past five years (**R4**).

2. Development of earthquake scenarios for humanitarian contingency planning

A related area of research at Durham has explored the generation and uptake of scientific information for decision-making around earthquake risk reduction. Despite the large volume of scientific research on faulting and earthquake hazard in Nepal, the resulting knowledge is used only in limited ways by donors and humanitarian organisations to raise awareness of earthquakes, and is not typically used at sub-national or community levels or to inform operational decisions (**R5**). Prior attempts to develop probabilistic seismic hazard assessments have suffered from inconsistency due to a lack of underpinning data, while deterministic earthquake scenarios have been exclusively targeted at the Kathmandu Valley (**R5**), ignoring the substantial risk in other areas of Nepal – a shortcoming that was highlighted by the 2015 Gorkha earthquake, which disproportionately affected rural mountainous areas via widespread landsliding (**R4**). These issues have hindered national-scale contingency planning for future large earthquakes by the humanitarian community. In response, Durham researchers developed a novel alternative hybrid approach that uses an ensemble of earthquake scenarios to represent all potential damaging earthquakes that could affect Nepal (**R6**). This resulted in a set of robust, plausible earthquake impacts that have been combined with estimates of vulnerability and isolation to identify areas that are at particular risk of disruption in the next large earthquake, irrespective of its size or location. The research highlighted particularly high levels of earthquake risk in western Nepal, due to a combination of very large potential earthquakes, a remote and distributed population, and poor infrastructure links to the rest of the country (**R6**).

**3. References to the research**

Note: underline indicates Durham employee during the research and/or at time of publication. Citation data are from Google Scholar, updated 1 Sept 2020.


R1: Petley, D.N., Hearn, G.J., Hart, A., Rosser, N.J., Dunning, S.A., Oven, K., and Mitchell, W.A. (2007) Trends in landslide occurrence in Nepal. *Natural Hazards* 43, 23-44, doi:10.1007/s11069-006-9100-3 *(Returned in RAE2008; 180 citations)*

R2: Milledge, D.G., Densmore, A.L., Bellugi, D., Rosser, N.J., Watt, J., Li, G., and Oven, K.J. (2019) Simple rules to minimise exposure to coseismic landslide hazard. *Natural Hazards and Earth System Sciences* 19, 837-856, doi:10.5194/nhess-19-837-2019. *(Returned in REF2021; 2 citations)*

R3: Williams, J.G., Rosser, N.J., Kincey, M.E., Benjamin, J., Oven, K.J., Densmore, A.L., Milledge, D.G., Robinson, T.R., Jordan, C.A., and Dijkstra, T.A. (2018) Satellite-based emergency mapping using optical imagery: experience and reflections from the 2015 Nepal earthquakes. *Natural Hazards and Earth System Sciences* 18, 185-205, doi:10.5194/nhess-18-185-2018. *(Returned in REF2021; 6 citations)*

R4: Kincey, M.E., Rosser, N.J., Robinson, T.R., Densmore, A.L., Shrestha, R., Singh Pujara, D., Oven, K.J., Williams, J.G., and Swirad, Z.M. (2020) Evolution of coseismic and post-seismic landsliding after the 2015 $M_w$ 7.8 Gorkha earthquake, Nepal. ESSOAr preprint, uploaded 8 Dec 2020, doi:10.1002/essoar.10505237.1. *(Accepted by Journal of Geophysical Research-Earth Surface)*

R5: Oven, K.J., Milledge, D.G., Densmore, A.L., Jones, H., Sargeant, S., and Datta, A. (2016) *Earthquake science in DRR policy and practice in Nepal*. Overseas Development Institute Working and Discussion Paper 10450. *(Peer-reviewed by two external reviewers; 6 citations)* https://www.odi.org/publications/10450-earthquake-science-drr-policy-and-practice-nepal (pdf is available from Durham)

R6: Robinson, T.R., Rosser, N.J., Densmore, A.L., Oven, K.J., Shrestha, S.N., and Guragain, R. (2018) Use of scenario ensembles for deriving seismic risk. *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.1807433115. *(Returned in REF2021; 8 citations)*

**4. Details of the impact**

The Government of Nepal and the UN recognise earthquakes and landslides, along with flooding and drought, as major obstacles to Nepal's national development priorities (evidence source **E1**). The Durham research on earthquake-triggered landslide hazard has underpinned key elements of the humanitarian response to the 2015 Gorkha earthquake by the Government, the FCDO, and the UN, and has been used to guide the Government's geohazard assessment and reconstruction efforts across the entire earthquake-affected region. In parallel, the research on earthquake scenario ensembles forms the scientific basis for national-scale humanitarian contingency planning for the next major earthquake by the UN, the Government, and all major international NGOs in the country. We examine each of these separate areas of impact below.

1. Quantification of earthquake and landslide hazard

In the immediate aftermath of the 2015 earthquake, the landslide maps (**R3**) and associated guidance notes based on prior experience (**R1**, **R5**) were used by a range of beneficiaries to understand the hazard and improve the immediate response. A full summary is provided by Datta et al. (2018; **E2**), but specific uses include:

- Provision of critical information on the likely evolution of the hazard to the FCDO in Nepal (**E3**) and to the UN Resident Coordinator's Office, which coordinates all UN activity in Nepal; this underpinned fact sheets on earthquake and landslide risk that provided operational guidance for all UN staff (**E4**);
- Identification of potential blockages to the road network and aid distribution by the UN Logistics Cluster and the World Food Programme (**E5**); and
- Development of landslide reports by the Nepal Earthquake Assessment Unit, which was run by the UN Office for the Coordination of Humanitarian Affairs to document the earthquake impacts (**E6**).

Durham research on landslide occurrence in Nepal (**R1**) and simple rules to minimise landslide exposure (**R2**) was subsequently used by the National Reconstruction Authority (NRA), Government of Nepal, to refine the landslide assessment methodology for a comprehensive Geohazards Assessment across the 14 worst-affected districts in 2016-2017. This effort, supported by People in Need (a humanitarian NGO) and UN-OPS (Office for Project Services), was the only comprehensive large-scale hazard assessment carried out by the Government after the earthquake, and classified the hazard severity in more than 1,000 settlements in order to guide reconstruction efforts and identify settlements in need of relocation. The research findings were used by the NRA geohazard assessment teams to identify safer relocation options (**E7**, **E8**).

The ongoing Durham-led post-earthquake landslide mapping and analysis (**R4**) has provided the Government of Nepal with its first comprehensive, up-to-date database of landslide hazard. This database is updated twice yearly and used to generate household-level landslide risk maps for more than 1 million individual houses across the 14 worst-affected districts. The landslide database and risk maps have had impact in at least four separate ways. First, they have been used by the Durable Solutions consortium, led by People in Need and funded by the FCDO, to provide a dynamic overview of landslide risk across the 14 worst-affected districts in support of relocation and reconstruction (**E8**). As stated by the Country Director of People in Need, '*To my knowledge, the Durham data is the only relevant information on the developing landslide risk across this broad area, and as such has been invaluable for our work in Durable Solutions. The decision making around landslide risk reduction since 2015 has inevitably been highly sensitive, and so having precise and reliable data has been essential for us, for the NRA and for wider donor-funded reconstruction programs. As of August 2020, Durable Solutions has supported the relocation of more than 11,000 people across nearly 2,500 households to safer locations, which includes the development of 32 entirely new 'integrated settlements' … Based around the* [Durham] *landslide mapping and modelling, we have engaged with local technical specialists in 62 municipalities across 6 districts to build capacity in risk informed decision making'* (**E8**).

Second, the database and maps have been formally adopted as the only current source of landslide hazard information within the Government's official disaster information platform, Bipad, maintained by the National Disaster Risk Reduction and Management Agency (NDRRMA), and the maps have been distributed to all 135 municipalities (*palikas*) within the 14 worst-affected districts (**E9**). As stated by the Chief Executive of the NDRRMA, '*The Durham data is the only on landslides data held within Bipad, and is presented in maps for use by palikas, who under our new federal system hold much responsibility for disaster risk reduction and management… This platform, and the scientific data within it, has been critical in articulating the impacts of disasters in Nepal and forms a valuable advocacy tool for disaster risk reduction and the NDRRMA*' (**E9**). Durham data on landslide occurrence and impacts have been incorporated by the NDRRMA into their 2020 monsoon preparedness plan, and have been presented to the Disaster Risk Reduction and Management National Council, chaired by the Prime Minister. The Chief Executive points out that '*the landslide susceptibility models generated by Durham have been used to articulate the scale and geography of the landslide hazard and risks that we face. This has allowed an initial prioritization of efforts such as messaging to palikas likely to be at highest risk during this period… Durham have been able to provide valuable data on the numbers of people exposed to landslides to really quantify and bring focus to the scale of this risk, and in particular how this has changed since the 2015 earthquake. I have presented these datasets at Council meetings, which has provided evidence into high level government discussions and decisions around priorities for landslide risk reduction. I note also that these data have then been more widely quoted by Ministers in their own work on the extreme impacts of landslides that have been experienced in 2020*' (**E9**).

Third, the Durham research has underpinned national-scale investment in earthquake reconstruction and disaster risk reduction by the FCDO. The FCDO Resilience and Inclusion Team Leader in Nepal states that the research '*has been essential in providing a barometer on the evolution of these risks. Specifically, it has allowed us to triage the most at-risk locations (be it individual site-specific assessments of houses, settlements, wards or municipalities at risk)*' (**E3**), in order to target earthquake response and resilience programming. Specifically, '*this information has been critical in supporting the Government of Nepal's National Reconstruction Authority (NRA), via our £63M post-earthquake reconstruction project where the data provides information on geohazards critical for risk-sensitive land use and wider development planning at the local level. It has also directly informed the £5M support to resettlement of vulnerable households project which has facilitated support to at-risk households in the aftermath of the earthquake*' (**E3**). The data have also been used to support the design and implementation of wider disaster risk reduction programming by the FCDO, including the use of '*evidence on landslide risks to underpin a focus on resilience in our recent £150M Local Infrastructure Support Programme business case, and in our £46M Strengthening Disaster Resilience and Responding to Humanitarian Emergencies in Nepal business case*' (**E3**).

Finally, Durham research on the persistently high landslide risk after the 2015 earthquake was specifically cited by the Directorate-General for European Civil Protection and Humanitarian Aid Operations as the rationale for the 2020-21 Humanitarian Implementation Plan for Nepal, a EUR2,000,000 programme that is focused on landslide risk analysis and management (**E8**).

<u>2. Earthquake scenarios for humanitarian contingency planning</u>

Durham research on earthquake scenario ensembles (**R6**) now underpins nationwide earthquake contingency planning by the UN Resident Coordinator's Office and the Government of Nepal. The Resident Coordinator leads the UN presence in Nepal and chairs the Humanitarian Country Team, which comprises all UN organisations and major international NGOs that are active in the country, organised into 11 thematic clusters. The earthquake scenario ensemble has been formally adopted by the Humanitarian Country Team as the basis for their nationwide earthquake Emergency Response Preparedness Plan (**E10**). The scenario ensemble provides the sole source of information on earthquake risk that underpins both the overall Plan and the detailed response plans from each cluster. As the Resident Coordinator points out, '*[e]ach cluster is now developing its own contingency plan, again underpinned by the scenario ensembles. This ensures that all clusters are using common figures for affected populations and areas of particular concern*' (**E10**).

Critically, the variability between different scenarios enables clusters to determine whether to plan for the average or the worst-case impacts, in terms of expected case loads. This conceptual advance provides a level of flexibility that would not be possible with a traditional scenario exercise, which typically considers only one or two potential earthquakes. The ensemble also allows the Humanitarian Country Team to anticipate logistical challenges in a future earthquake and to identify priority locations for preparedness actions, such as stockpiling of critical supplies. At the same time, the research findings that the impacts of the 2015 earthquake were particularly acute in remote mountainous areas (**R3**, **R4**), and that a future earthquake is likewise expected to be highly disruptive in rural areas beyond the Kathmandu Valley (**R6**), have helped the Resident Coordinator's Office to focus on national-scale preparedness, allowing planning to be both more targeted and more efficient:

'*To my knowledge, we are unique among Resident Coordinator's Offices in having such a close and sustained relationship with academic researchers. It has allowed us to use scientific modelling for our preparedness and response plans, this has given us credibility with the clusters and humanitarian partners. The research which has been developed and shared continuously has meant that we can target our planning both geographically but also based on needs and vulnerabilities, which again allows the humanitarian community to use the limited resources at their disposal much more efficiently.*' (**E10**)

The Resident Coordinator is now working to develop joint earthquake response plans with the Government of Nepal, again underpinned by the scenario ensemble (**E10**). Beyond Nepal, the scenario ensemble approach to earthquake planning is applicable elsewhere in South Asia, and Robinson led a similar earthquake scenario and contingency planning exercise with the Resident Coordinator's Office in Bhutan in 2018 (**E10**).

**5. Sources to corroborate the impact**


E1. United Nations Country Team Nepal (2017), UN Development Assistance Framework for Nepal 2018-2022.

E2: Datta, A., et al. (2018) The role of scientific evidence during the 2015 Nepal earthquake relief efforts. Overseas Development Institute Report 11044, available at https://www.odi.org/publications/11044-role-scientific-evidence-during-2015-nepal-earthquake-relief-efforts.

E3: Testimony from the Resilience and Inclusion Team Leader, Foreign, Commonwealth and Development Office, British Embassy Kathmandu, 16 December 2020.

E4: For example, see the Humanitarian Country Team Meeting Minutes, 2 May 2015.

E5: For example, see the World Food Program Logistics Cluster Landslide Distribution Map, Sindhupalchok District, 23 Sept 2015.

E6: For example, see the Nepal Earthquake Assessment Unit Weekly Situation Update, 10 July 2015.

E7: National Reconstruction Authority, Government of Nepal, Geohazard Assessment Programme Technical Manual Form 6, Relocation Options Guidance. 2016, no date.

E8: Testimony from the Country Director, People in Need – Nepal, 18 December 2020.

E9: Testimony from the Chief Executive Officer, National Disaster Risk Reduction and Management Agency, Government of Nepal, 4 January 2021.

E10: Testimony from the UN Resident Coordinator in Nepal, 30 July 2020.