Increasing Resilience to Natural Hazards in Earthquake Prone Regions in China (IRNHiC): a UK-China collaboration

About this report

This report summarizes the achievements of, and lessons learnt from, the Increasing Resilience to Natural Hazards in Earthquake Prone Regions in China (IRNHiC) programme. It was prepared for the Natural and Environment Research Council by a team from International Network for the Availability of Scientific Publications (INASP), the Overseas Development Institute (ODI), and the University of Oxford:

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The report begins with a background overview of the IRNHiC programme, situating this within the context of the earthquake hazard and risk environment in Eurasia, and the Chinese context in particular (Section 1). In Section 2, we summarise the six IRNHiC projects, outlining the approaches they took to address different issues across the hazard chain, and their key achievements. Section three outlines key reflections and lessons learned, drawing on discussions at the final IRNHiC conference in Beijing in March 2019. The report closes with recommendations about future directions for such programmes (Section 4).

Acronyms

BRI	Belt and Road Initiative
CBDRR	Community-based disaster risk reduction
CEDDRIC	Community-based earthquake disaster risk reduction in China
ESRC	Economic and Social Research Council (UK)
EwF	Earthquakes Without Frontiers
DRR	Disaster risk reduction
INASP	International Network for the Availability of Scientific Publications
IRNHiC	Increasing Resilience to Natural Hazards in China
NERC	National Environmental Research Council (UK)
NSFC	National Natural Science Foundation of China
ODI	Overseas Development Institute
REACH	Resilience to Earthquake-Induced Hazards in China
RESIST	Resilient Economy and Society by Integrated Systems Modelling
STINGS	Seismic hazard and Tectonics in Ningxia, Gansu and Shaanxi
PAGER-O	Pan-participatory Assessment and Governance of Earthquake Risks in the Ordos Area
PURE-C	Probability and Uncertainty in Risk Estimation and Communication
RCUK	Research Councils UK
TR	Transdisciplinary research

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1. Introduction

1.1 Background

Earthquakes have cost over 2 million lives since the beginning of the 20th century, with two-thirds of deaths occurring across the Alpine-Himalayan Belt, which stretches from Eurasia to southern Europe. The attendant damage to essential infrastructure, crippling of local economies, disruption of livelihoods, and mass displacements of people often set back development in the affected regions by decades. It is estimated that by 2050 about 2 billion people in the developing world will be exposed to serious earthquake risk. Developing countries at risk of earthquakes and earthquake-related hazards face a 'wicked problem': they are densely populated nations experiencing rapid urbanization, and need to reduce poverty and promote development at the same time as dealing with a hazard that is hard to detect, and has little historical record.

This problem was addressed by collaborations between Chinese and UK researchers across six projects funded through Increasing Resilience to Natural Hazards in China (IRNHiC) programme. Projects took a transdisciplinary[1] approach to exploring multiple natural hazards across the full spectrum of the earthquake hazard chain and to improving the uptake of and responses to scientific advice. IRNHiC partners included UK and Chinese universities as well as Chinese government agencies. In the research teams, earth science experts worked with engineers, architects, sociologists, social workers, earthquake safety practitioners, political scientists, and disaster risk reduction policy experts. The results offer a platform for effective new scientific methods and technologies that will increase resilience to earthquakes in China and across the region of the Belt and Road Initiative.

1.2 The IRNHiC Programme

IRNHiC was a £5M, three-year programme, active from 2015-2019 and built on NERC/ESRC's earlier Increasing Resilience to Natural Hazards (IRNH) programme. The goal of the programme was to promote economic development and welfare in China by increasing resilience through reduction of risks from multiple natural hazards. Resilience is regarded, in this context, as the capacity of communities (i) to survive or adapt to the effects of earthquakes and their secondary hazards; (ii) to maintain certain basic functions and structures in their immediate aftermaths; and (iii) to recover after such events.

The aim was to integrate natural and social science approaches across the programme; and to foster stronger China-UK collaboration involving transferable research, protocols and approaches that could apply to both countries. Funding came from the National Natural Science Foundation of China (NSFC) and the Natural Environment Research Council (NERC) and Economic and Social Research Council (ESRC) of the UK. The programme supported six Sino-UK teams that integrated natural and social science research with the goals of increasing reliable knowledge on the fundamental processes underlying earthquake-related hazard and risk, and to improving the uptake of and responses to scientific advice.

Several characteristics of the design and implementation of the programme were instrumental in achieving clear impacts, by informing policy and building capacity. Effective UK-China

[1] The term transdisciplinary, as used in this report, refers to an approach to problems that are socially relevant, and often complex. Transdisciplinary research (TR) begins with the societal problem and then assembles the disciplines necessary to solve it. Researchers and stakeholders collaborate, in a way that transcends disciplinary boundaries, to design the research programme. The ultimate purpose is to ally the best available evidence with the reality of policy making to identify a course of action that will benefit society (*e.g.*, in the present case, strategies for the mitigation of earthquake-related risks).

partnership was made possible by similar processes of assessing research grant applications, predicated upon stringent and robust peer review procedures, and by the flexibility of both sets of funders in implementation of the programme. The transdisciplinary nature of the programme provided the space to test new approaches to research and to the uptake of research results. Perhaps most importantly, the concentration on a single country generated exploration of multiple natural hazards along whole hazard chains, within a single socio-political context; this allowed deeper exploration of potential strategies to mitigation of the risks.

1.3 Chinese context

China is one of the most hazard-prone countries in the world, suffering multiple natural hazards, with a many severe losses in past disasters[2]. Seismic hazard is pervasive; many historical earthquakes caused tens of thousands of deaths, and several had death tolls in the hundreds of thousands, including the 1556, Huaxian, earthquake, which led to over 800,000 deaths, the greatest number ever recorded[3]. Rural populations and minority groups inhabit most of the areas frequently affected by earthquakes, with disaster response and reconstruction efforts requiring more resources in these areas because of lower economic development.

Against this background, the six IRNHiC projects generated knowledge that will inform practices to increase resilience to earthquakes in China. That experience will prove invaluable to China as it deepens engagement with countries in the Alpine-Himalayan Belt through the Belt and Road Initiative (BRI) – an initiative of the Chinese government to promote trade and economic growth connecting Asia, Europe and the rest of the world, with some estimates expecting investments to surpass $1 trillion in the coming years[4].

The ancient Silk Roads followed routes across the mountainous terrain of the Alpine Himalayan Belt, with population centres growing up around sources of water that are associated with active faults. Many of those centres, now major cities, were destroyed by earthquakes in the past when their populations were small. The planned BRI infrastructure will cross many of the ancient routes in this region, which probably suffered earthquakes about which the historical record is silent. The outcomes of IRNHiC will support all the affected nations in decreasing the earthquake risks of their investments along these new trade routes.

2. Projects

2.1 Community-based earthquake Disaster Risk Reduction in China (CEDRRiC)

National Disaster Reduction Center of China & Chang'an University and Wuhan University & Universities of Durham and Newcastle, UK

The project focused on hazards posed by earthquake-triggered landslides, which have been a major feature of earthquakes in China, and are also one of the most poorly constrained parts of earthquake hazard as it is difficult to anticipate the spatial and temporal characteristics. The project assessed the distribution and characteristics of earthquake-triggered landslides in the Loess Plateau region of China, focusing in particular on those triggered by the devastating 1920 Haiyuan earthquake. The research showed how earthquake-triggered landslides in loess differ

[2] Shi, P., Liu, J., Yao, Q., Tang, D, and Yang, X. 2007. Integrated disaster risk management of China. http://www.oecd.org/dataoecd/52/14/38120232.pdf.
[3] Zhang, P., Yang, Z., Gupta, H., Bhatia, S. and Shedlock, K., Global Seismic Hazard Assessment Program (GSHAP) in continental Asia., Annali di Geofisical, **42**, 1167-1190, 1999.
Zhang, P., Deng, Q., Zhang, G., Ma, J., Gan, W., Min, W., Mao, F. and Wang, Qi. Active tectonic blocks and strong earthquakes in the continent of China, Science in China (Series D), **46**, 2003, DOI: 10.1360/03dz0002
[4] https://www.morganstanley.com/ideas/china-belt-and-road

in important ways from those in areas underlain by harder rock, especially in terms of size, runout, and spatial distribution. This work led to a new approach to modelling landslide impacts, which contributed to the earthquake scenario in the PAGER-O project. In parallel, the project also sought to understand community-based disaster risk reduction (CBDRR) efforts in China, which are a critical element of current efforts to address this problem. The project reviewed the National Comprehensive Disaster Reduction Demonstration Community programme administered by the Ministry of Civil Affairs. The review confirmed widespread impacts on disaster preparedness, but also revealed important gaps between community perceptions and the realities of the hazards, and identified differences between urban and rural communities that could be addressed by the programme. Similar CBDRR efforts in Nepal open the possibility for collaboration on this topic. The parallel science and social science research created cross-pollination of ideas and led to the development of a simple but accurate method of landslide risk estimation: the skyline to local level angle for landslide risk estimation.

2.2 Resilience to Earthquake-Induced Hazards in China (REACH)

Chengdu University State Key Laboratory of Geo-hazard Prevention & Cardiff University, UK

After an earthquake, multiple interacting hazards act in a chain to increase risk and decrease resilience. Debris flow as a result of aftershocks and new landslides creates river sedimentation that builds up for years to decade after a main shock. This can lead to landslide dams upstream of rivers and flooding. The project demonstrated these are often grossly underestimated in post-earthquake rebuilding efforts, leading to 'maladaptation'. The project also focused on the spatial and temporal development of earthquake risk through detailed understanding of the evolution of social vulnerability in the face of these post-earthquake hazards. REACH resulted in improved understanding of social vulnerability in the Chinese context, showing how it changes as the hazard chain evolves: for example, villages in valleys with initially low social vulnerability become progressively more vulnerable due to post-earthquake debris flow and flood events. It is particularly important to recognize that the management of risk and resilience is strongly dependent on the scale of the administrative unit and the scale of hazards. At any one time, small administrative units will be exposed to contrasting elements of the hazard chain; equally, a single unit will be exposed to different elements as the hazard chain develops over time. The high spatial and temporal resolutions of the project's datasets provide novel ways to characterise the mechanisms underlying the evolution of multi-hazard events in Wenchuan. The improved understanding of debris flows and their effects on social vulnerability in the context of Wenchuan offers possible routes to developing adaptive strategies for risk mitigation in other post-earthquake environments.

2.3 Seismic hazard and Tectonics in Ningxia, Gansu and Shaanxi (STINGS)

Sun Yat-sen University & Institute of Geology, China Earthquake Administration, Beijing and Lanzhou & Shaanxi Earthquake Administration & Universities of Oxford, Cambridge, and Durham, UK.

This project improved the understanding of active tectonics in the region at the intersection of the Ordos block and the north-eastern Tibetan plateau, increasing local government agencies' capacity to assess seismic hazard, and providing insights into the geodynamics of continental interior. Using state-of-the-art geological, digital, and satellite technology, detailed investigations were completed for 10 major historical earthquakes and slip-rates and recurrence intervals on over 20 major fault segments were measured. These studies have both re-calibrated the magnitudes of the earthquakes and identified earlier, pre-historical, earthquakes on the faults. Data from the 1568 Shaanxi Gaoling earthquake were used as input to the PAGER-O scenario for Weinan. The project also compiled approximately 3M words of historical records of shaking in the region over the past 2000 years. These

records have been interpreted in the light of modern earthquake science and knowledge of the limitations and errors inherent in such records. The outputs of these studies have been combined to produce — for the first time — time-dependent probabilities of M≥6.5 earthquake in next 50 years for the region, which is designed for use by various agencies for social and economic planning, earthquake hazard reduction, and increasing resilience to natural disasters.

2.4 Pan-participatory Assessment and Governance of Earthquake Risks in the Ordos Area (PAGER-O)

Institute of Geology, China Earthquake Administration & Shaanxi Earthquake Agency, Xian & Overseas Development Institute, London & Universities of Oxford and Durham, UK.

The project aimed to identify opportunities for improving earthquake resilience in the Ordos area by bridging the gaps between science and policy and top-down and bottom-up approaches to disaster risk reduction governance in China. The work used a new approach to develop an earthquake scenario for Weinan City, bringing together a trans-disciplinary international team of researchers and various local stakeholders to co-identify earthquake risk, co-explore pathways to earthquake resilience, and motivate co-action for earthquake risk reduction. Scientific and technical investigations were adapted to the specific context of a repeat of the 1568 Gaoling earthquake, whose causative fault and ground shaking were documented as part of the STINGS project. The resulting scenario is now available (in Chinese and English) as (i) a graphic novel for public education and (ii) a handbook for local government staff, to stimulate discussions, to foster consensuses, and encourage collaborative action to strengthen both top-down and bottom-up earthquake DRR pathways. These documents are already being used by the Earthquake Administration of Huazhou district of Weinan in outreach activities.

2.5 Resilient Economy and Society by Integrated Systems Modelling (RESIST)

Institute of Mountain Hazards and Environment, Chengdu & Bristol University, UK

The project created models to better project debris flow, and used these in specific case study sites in China and overseas to improve monitoring and warning systems. The team developed a set of numerical models for dynamic multi-hazards risk assessment, which combined: (i) a module modelling individual and interacting multi-hazards (ii) city system module that can map hazards onto the distribution of city infrastructure (iii) A module for time-dependent risk assessment that can simulate the evolution of the interaction between hazard and population during an emerging event. This system offers decision-making supports for urban hazard management, sustainable tourism, and resilient infrastructure. The model has attracted interest from policymakers and is already being used in China, where it has contributed to the development of two engineering standards for mudslide and debris flow prevention, and in neighbouring countries. In Baihetan hydropower plant, it has been implemented as a three-level monitoring and warning system which has successfully completed three annual prediction cycles, with an annual report to central and local government. In Bhote Koshi, Nepal, the model has been used in connection with the BRI where local authorities were unable to confirm the causes of damage in relation to hazard events for insurance purposes; the model provided evidence that the damage was caused by earthquake-related debris flow which allowed the local government to access the compensation payout.

2.6 Probability and Uncertainty in Risk Estimation and Communication (PURE-C)

Institute of Geophysics, China Earthquake Administration & Edinburgh University, UK.

This project focused on developing a new method and software to assess probability and uncertainty in risk estimation. This was addressed through four main activity strands:

calibration of historical data on seismic sources; ground motion prediction; production of time-dependent seismic hazard maps; and communication of risk through engagement with government officials and communities. The source parameters for several historical earthquakes were re-evaluated taking account of source complexity and geology and topography. The results could contribute to resilience by helping target the search for as-yet undiscovered historical records, and by generating more accurate probabilistic seismic hazard maps. Social science work revealed that CEA probabilistic maps support operational decisions on construction, but stakeholders are less confident of using forecasts when probabilities are low.

3. Comments on the IRNHiC programme

3.1 Introduction

The IRNHiC programme aimed to improve China's resilience to natural hazards through knowledge of the fundamental processes, underpinned by basic science, and to improve the uptake of, and responses to, scientific advice in collaboration with the communities at risk. The programme encouraged investigators to adopt a co-productive approach to research, involving a framework for sharing knowledge and values between natural scientists, social scientists, policy makers, civil society and other stakeholders – for brevity, this report has used the term `transdisciplinary research' to describe that process.

This section outlines lessons learned about this process, which emerged from discussions during the final IRNHiC conference in Beijing in March 2019, where all six projects gathered with key stakeholders to report on their results. These lessons bear upon: the implications of a transdisciplinary approach for the research process itself; the added complexity of taking such an approach in an international context; the team characteristics, capacities; and the approaches to funding that might best support international transdisciplinary research.

3.2 Carrying out transdisciplinary research

IRNHiC projects emphasised the importance of starting with the societal problem; this requires a fundamentally different way of working because the programme is defined, from its inception, by societal goals rather than by the research agendas of individual disciplines.

Operating outside traditional disciplinary boundaries required a substantial shift in long-established patterns and cultures of working. Several IRNHiC members felt, initially, that they were pushed outside the accepted methodological standards and conventions of their disciplines in order to work in this way. However, there was a strongly shared reflection across the projects that reaching outside existing conventions was a critical step in enabling a truly collaborative research process

Scalability Many projects addressed towards resilience have a strong focus on community-based DRR and experience difficulties in making their results useful to larger populations. The CEDRRiC project identified gaps (i) between top-down policies and their implementation, which is bottom-up and (ii) between community perceptions and the realities of the hazards. The narrative scenario of PAGER-O was designed specifically to bridge those gaps. This project – a first of its kind in China – was co-produced between the project team, the Weinan government and the Shaanxi EA, and its recommendations are now being adopted. CEDRRiC emphasised the potential benefits of cross-border collaboration in CBDRR, particularly with Nepal. Scalability remains an issue, however, because much social research focuses on the nuances, complexities, and heterogeneity of settings, which are difficult to distil into large-scale solutions.

3.3 International collaboration

Design of the Research Team was felt by many to be the single most important element in navigating the challenges of international transdisciplinary research. Credibility of team members is fundamental. That comes from track records of the individual participants: research profiles, roles in defining strategy within their own fields, effective interaction with policy makers, with other stakeholders, and with other disciplines. The team must be led by people who are committed to a transdisciplinary way of working, and team members should, in general, be willing to modulate their habitual modes of research to accommodate the wider goals of the project. Transdiciplinarity is not for everyone, however, and team leaders need to be able to negotiate the tensions between individual disciplines and practices that inevitably arise in co-designing such a process.

Trust within project teams was felt by many to be an essential aspect of IRNHiC's ability to use the transdisciplinary approach described above, and this was described as arising only from gradual, long-term and sustained engagement. Cultures of research, and of the interactions between researchers and policy makers, vary widely between countries, and friction between these cultures can delay the building of trust. Some projects within IRNHiC benefitted from trust that had been developed over decades of previous collaboration, and those with strong pre-existing links had little difficulty in setting up in-country scientific research programmes that achieved positive results within the 3-year span of the programme. Other projects whose members had less experience working together struggled to overcome this challenge.

Impact. All the projects expressed the view that, in the Chinese context at least, international collaborations would be impossible without Government support and approval. Such support must go beyond simply providing the funding resources, and should provide the methods for delivery, and for evaluation of the project's outcomes. Without such commitments from the authorities at city, provincial, or national level – as appropriate – uptake of the research will be limited or non-existent.

3.4 Replicability in China and beyond

Transdiciplinary research is not common in China. Disciplinary strengths are high, but cross-disciplinary links are often difficult to form and the fora in which decisions are made are more formal and hierarchical than in other countries where TR has been applied. Nevertheless, project members, and particularly early-career researchers, were encouraged by successes in bringing scientists of different disciplines together with policymakers and operational agencies. They felt that TR could be more widely applied to both natural hazards and other societal challenges. The present structures provide ample opportunity for collaborative and collective decision making, and there is potential to evolve approaches to dialogue and engagement across academic, policy and operational agencies that would integrate effectively the currently disjointed science and policy enterprises.

Technical approaches developed in IRNHiC are replicable in other parts of China. For example, the scenario approach developed by PAGER-O is currently being explored for applications in other provinces by CEA. Shaanxi EA is planning to introduce the approach in their next five-year earthquake DRR planning process, and Zhejiang provincial EA has also requested information on the scenario approach from the Chinese principal investigator. A key aspect of this approach is that, as well as being transferrable from one region to another, it also enables many different communities to be reached in a single exercise, overcoming the problems of scalability associated with purely bottom-up efforts.

3.5 Funding Modalities

Flexibility The requirement to reach beyond established ways of working applies not only to the researchers but also to the funders of transdisciplinary work. IRNHiC was a bold experiment by its funders at NERC, ESRC, and NSFC to try to achieve societal impact through new funding streams. The projects all recognised and applauded this attitude, particularly in the allocation of resources in response to natural events and to the evolution of the projects. All the UK investigators felt that they were helped to achieve such flexibility by the admirable advice and support of the INRHiC advisory team.

Although both RCUK and NSFC stretched their existing mechanisms to deliver this innovative programme, significant difficulties nevertheless arose from the constraints that remained.

Funding levels. It appears that, whereas NERC/ESRC wished to stimulate transdisciplinary projects, which by their nature would be broad, NSFC preferred projects that were more tightly defined, with a consequent constraint on the level of funding. That constraint resulted in a programme of small projects that were, inevitably, fragmented. The Research Councils attempted to bring teams together at the start of the programme, although no resources were available for this. Collaboration worked well between the three teams that had emerged from the preceding EwF programme, but less well with the others. Fewer larger projects, and/or additional resources to facilitate better collaboration between them might have led to more effective outcomes.

Duration of Programme. Building a transdisciplinary research team takes time. The short period between the announcement of opportunity for the projects and the deadline for submission of proposals meant that there was little time to build teams in areas where a team did not already exist. In such cases, a year or more during the project was spent on team-building, which investigators felt was not an efficient use of funds. The project leaders also felt, in retrospect, that the duration of the programme imposed an unrealistic expectation: that teams should develop new relationships, carry out transdisciplinary research, develop new knowledge, and transfer it into usable practice and policy – all within a 3-year time frame.

Legacy of Programme. After continual investment in relationships over the three-year duration of the programme – and in some cases several years prior to that – all of the projects expressed concern about the legacy of IRNHiC. The end of the programme brought to a halt relationships that had been carefully nurtured, and which had begun to deliver benefits to society. Stakeholders who had invested in this process were inspired to hope for continuing progress in combating the challenges they face. These hopes will not come to fruition.

4. Conclusions and recommendations

China has world-leading capacity in earthquake hazard research and in response to earthquake disasters, while the UK has a strong research programme in geohazards, which is distinctive in its global scope. The resultant collaboration between Chinese and UK researchers under the IRNHiC programme produced valuable knowledge, tools, products, and impacts (Section 2).

The IRNHiC programme was an innovative step, for both its UK and Chinese funders, being their first co-funded and explicitly transdisciplinary research programme. Societal problems lay at the centre of the research and – in so far as resources permitted – successful projects brought all relevant disciplines to bear on those problems. This approach is of fundamental importance if scientific knowledge is to inform effective disaster mitigation strategies (Sections 3.1—3.3).

Investigators in the six IRNHiC projects emphasised the central importance of building and maintaining strong relationships of trust, both within research teams and with community and government stakeholders (Section 3.3).

Through this approach, the IRNHiC programme laid the foundation for a new way of working to reduce societies' vulnerability to geohazards in China, in the region of the Belt-and-Road Initiative, and throughout Eurasia (Section 3.4).

There were some problems that, if they were to be addressed, would make a successor programme more effective (Section 3.5).

- Scale: The goal of the programme was to stimulate projects in which researchers from a wide range of disciplines interacted closely with stakeholders. Such projects are necessarily broad, but the maximum level of funding available was not sufficient to support that breadth and each project was vitiated by the need to fit within a budget of £400,000 over 3 years.
- Duration: The time between announcement of IRNHiC and the closing date for proposals (4 months) was too short for the formation of new multi-disciplinary teams; this led to loss of time in team-building during the projects. Furthermore, the 3-year limit on project duration was unrealistic for the formation of a new teams, co-production of programmes with stakeholders, the generation of new knowledge, and its effective transfer into policy and practice.
- Legacy: Programmes such as IRNHiC, with their ODA-related agendas, contribute to the well-being of developing nations, but the three-year duration is long enough merely to raise hopes of improvement – not to deliver a lasting legacy. Unless such contributions are sustained, they will come to be seen as short-lived and empty gestures, like so many western interventions in the affairs of developing nations.

There are nevertheless many positive indicators from IRNHiC for future activities. The emphasis on projects that contribute directly to societal problems has been surprisingly productive, and could be seen as adding to the UK's `soft power'. Such activities should be continued and widened, bearing in mind the caveats above.

Other Research Councils can potentially contribute greatly to these activities, for example many aspects of earthquake risk rely on the development of innovative and context-specific engineering and architectural solutions, while understanding the long time scales of the past evolution of vulnerability and its future mitigation require the perspective of historians and archaeologists.

If a continuation were to be in China, then consideration should be given to forming closer links:

- between UK and Chinese research funders, and
- between research funders, research organizations, and the relevant ministries.

The approaches developed in IRNHiC are transferable both to other geohazards, and to other Newton countries.

The applications to DRR of recent advances in science technology, such as machine learning, remote sensing, big data, are in their infancy. These offer huge potential benefits.