Integrated Research on Disaster Risk (IRDR)

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Abstract:

Disasters disrupt normalcy and present challenges for development policies. The impacts of any disaster–whether triggered by climate change, natural hazards or other man-made events–can be compounded by decisions that intentionally or unintentionally amplify rather than reduce damage. Disasters have impacts across all sectors, necessitating multi- and trans-disciplinary research. The Integrated Research on Disaster Risk Programme (IRDR) aims to provide both the conceptual underpinnings for an integrated research framework to achieve disaster risk reduction, as well as the organizational scaffolding to support capacity building and the advancement of this vision globally. Wisdom on science and technology for disaster risk reduction emerging from the IRDR Programme falls into four thematic areas: (1) disaster loss data collection, (2) forensic investigations of collected data, (3) interpretation of risk factors, and (4) the analysis of integrated research on disaster risk reduction. Across these, IRDR has developed trans-disciplinary, multi-sectorial alliances for in-depth, practical disaster risk reduction research studies to support the implementation of effective evidence-based disaster risk reduction policies and practices. Assessments suggest that multi-sector strategic partnerships are essential to enhance capacity development and to enable effective policy making based on evidence.

1 Introduction

Disaster risk understanding requires an integrated approach to natural and human-induced environmental hazards, through convergent natural, socio-economic, health, and engineering sciences. A truly integrated approach to disaster risk research requires the inclusion of behavioural sciences and analysis, to understand the roles of risk interpretation and communications, and to assess public and political risk decisions and behaviours, in order to reduce risks. Integrated disaster risk research engages multiple scales (local to global); stakeholders (experts, professionals, government officials, and communities at risk); bodies of knowledge (scientific, local methodological approaches; and areas of application/implementation (planning, sustainable development, and policy) (Melanie et al., 2015). With this philosophy, the Integrated Research on Disaster Risk programme comprises an international ensemble of scientific expertise, practice, policy bodies, methodologies, and knowledge to achieve disaster risk reduction globally.

1.1 What is the IRDR Programme?

The Integrated Research on Disaster Risk (IRDR) programme is an interdisciplinary programme established by the International Council for Science (ICSU) following its approval at the 29th ICSU General Assembly in 2010. From its inception, the Programme has been delivered collaboratively by the United Nations Office for Disaster Risk Reduction (UNISDR) and the International Social Science Council (ISSC) (IRDR, 2017). The ISSC and ICSU merged in 2016 to become the International Science Council (ISC). The purpose of the IRDR programme is to strengthen the use of science and its interface with policy and practice to address the increasing challenges posed by natural and human-induced environmental hazards. The risks to communities from environmental hazards often stem from interactions with and impacts on the built environment, as illustrated in the case studies in this chapter. Figure 1 shows the foundational multi-hazard framework of IRDR to understand and characterize risk, risk production processes and governance, and damage and losses.

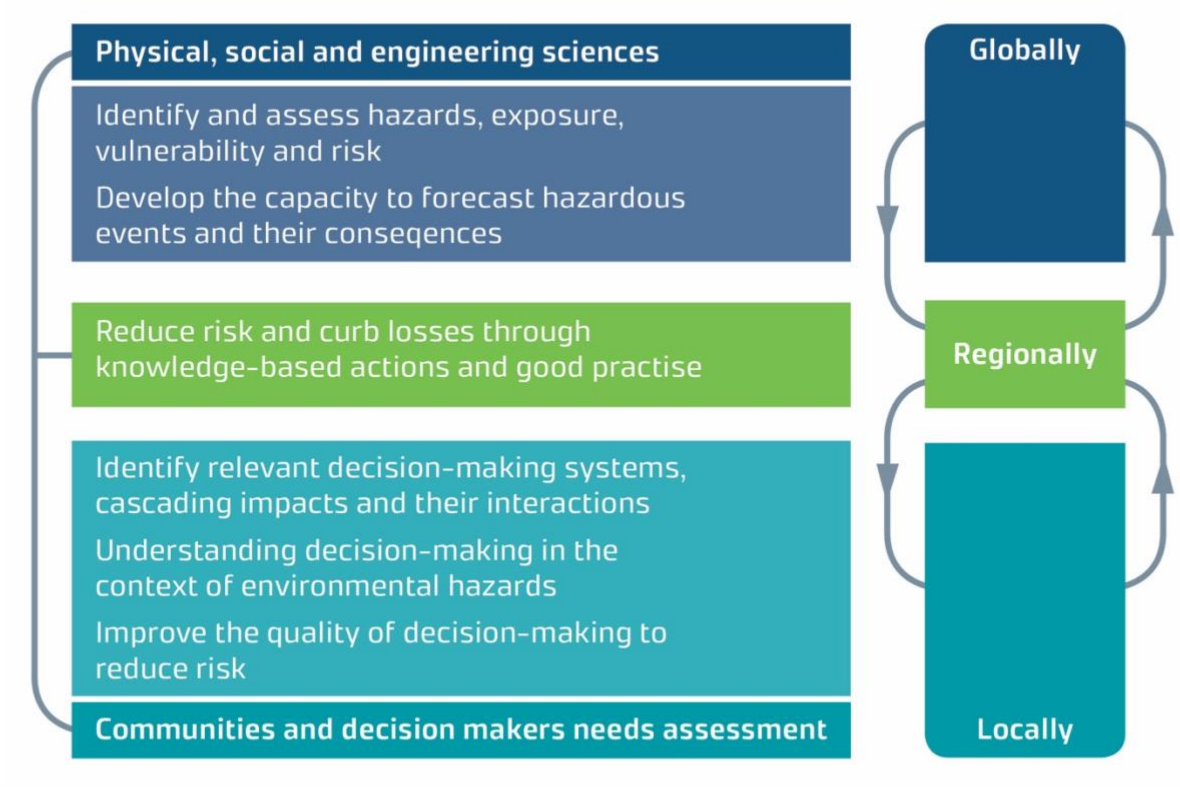

Figure 1 Science behind IRDR

IRDR's mission is to develop trans-disciplinary, multi-sectorial partnerships for comprehensive, practical disaster risk reduction research and the implementation of evidence-based disaster risk policies and efficient practices (IRDR 2018). IRDR promotes the development of capacity around the world to address hazards and make informed decisions on actions to reduce their impacts. Figure 2 shows the institutional structure of IRDR; the International Program Office (IPO) reports on its operations to the IRDR Scientific Committee (SC) on programme implementation, and reports to the host and donor (Institute of Remote Sensing and Digital Earth (RADI)/Chinese Academy of Sciences (CAS) and the China Association for Science and Technology (CAST)). IRDR promotes and supports associated projects proposed by SC members or International Centres of Excellence (ICoE), which are coordinated in close collaboration with the IPO. The IPO maintains close ties with affiliated ICoEs, and with IRDR National Committees (NC) and Regional Committees (RC), to promote activities throughout the IRDR network. Figure 2 also names three of four initial IRDR working groups, described in section 1.2.

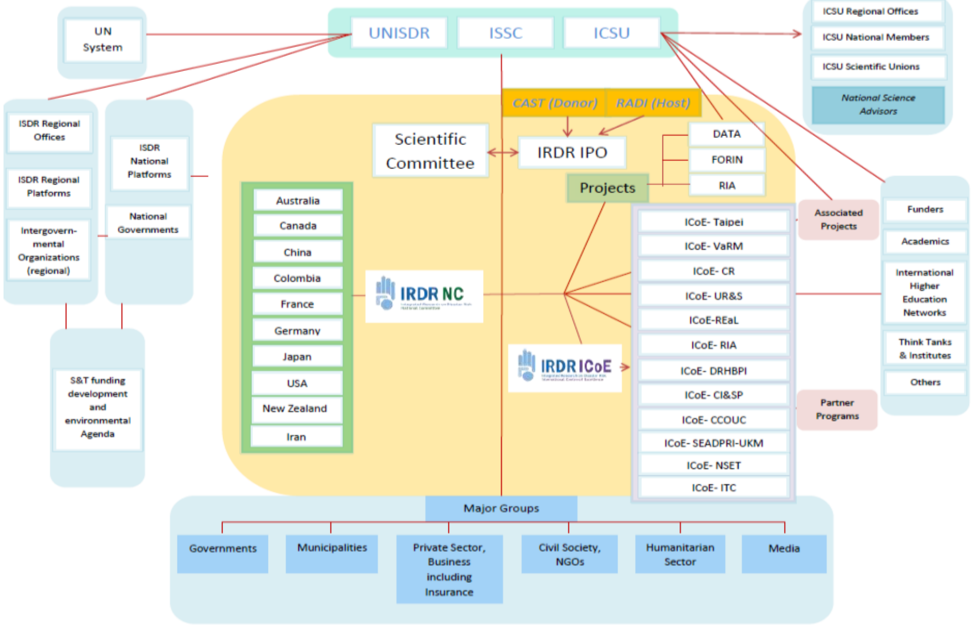

Figure 2 Operating structure of IRDR (IRDR, 2018)

1.2 IRDR Working Groups

Initially the IRDR Programme included four IRDR Working groups, introduced here and described in detail below. Additional working groups on coherent disaster risk reduction, climate change adaptation, and sustainable development goals were initiated in 2018.

1.2.1 The Assessment of Integrated Research on Disaster Risk (AIRDR)

The AIRDR working group contributes to the development of an integrated research approach to disaster risk through systematic reviews and critical assessment of global research on disaster risk (IRDR, 2014a, 2018), and disseminates its findings to researchers globally (see Section 2). Results from the AIRDR working group to date have supported the identification of a longer-term science agenda on assessment of integrated research on disaster risk for both the research community and funding entities.

1.2.2 Disaster Loss Data (DATA) project

The DATA working group brings together loss data stakeholders in order to build a network of networks to reflect the data requirements in the Sendai Framework and take advantage of synergies between other global agreements (i.e. Sustainable Development Goals (SDGs) (United Nations 2015), the Paris Climate Agreement (UNFCC 2015), and the Habitat III New Urban Agenda (United Nations Habitat III 2016). Data infrastructure for disaster research connects disaster-related datasets of observations, analyses and statistics, minimum data standards, and data-sharing plans. Hence IRDR's Disaster Loss Data (DATA) project is designed to support information dissemination, networking and collaboration with a growing network of stakeholders from different disciplines and sectors to study issues related to the collection, storage and dissemination of disaster loss data. The working group links emerging research programmes, and develops collaboration models through social media and citizen participation (IRDR, 2018). The DATA project aims to be a reference point for sharing DATA news, proposals, results, and ideas; to identify the quality of existing data and what data are needed to improve disaster risk management; and to develop recognized standards or protocols to reduce uncertainty in the data (see Section 3).

1.2.3 Forensic Investigations of Disasters (FORIN)

The FORIN working group develops, disseminates and implements systematic disaster research that seeks to identify and explain the underlying causes of disasters, including the growth in magnitude and frequency of very large disaster events (see Section 4). The key output from this working group to date is a methodology built around case studies in keeping with IRDR research objectives (Burton, 2010; Oliver-Smith et al., 2016). The FORIN case studies can be integrated into various disciplinary approaches (IRDR, 2018).

1.2.4 Risk Interpretation and Action (RIA)

The Risk Interpretation and Action (RIA) working group focuses on the question of how people — both decision-makers and ordinary citizens - make decisions, individually and collectively, in the face of risk (see Section 5). Decision making under conditions of uncertainty is inadequately described by traditional models of rational choice. Instead, attention needs to be paid to how people's interpretations of risks are shaped by their own experiences, personal feelings and values, cultural beliefs and interpersonal and societal dynamics (Eiser et al., 2012). Among others, the IRDR RIA International Centre of Excellence advances knowledge generation in this domain, with a focus on emerging and everyday risks in different geographies (IRDR, 2018).

2 Assessment of Integrated Research on Disaster Risk (AIRDR)

The IRDR Assessment of Integrated Research on Disaster Risk (AIRDR) project is intended to be a collaborative, global network for researchers to collect, assess, and disseminate information about disaster risk reduction (Gall *et al*, 2014a,b,c, 2015; IRDR, 2018). Integrated research examines problem-focused, socially-driven research questions that cannot be adequately addressed by one or a small number of research disciplines, or without collaborative problem solving and real-world engagement of non-academics. Integrated research permits a more comprehensive understanding of the construction of a particular disaster situation, context, or problem and also provides policy-relevant information for social interventions designed to reduce risk. An integrated research approach requires diverse epistemologies, theories, and methodologies, with no prior assumptions about the primacy of each in addressing the problem.

2.1 Current state of the science on integrated research on disaster risk

> *"The only way to achieve a real understanding of risk and disasters, the ways in which society understands them and reacts to them, and our opportunities for risk reduction, is the use of more complex protocols that require greater levels of conceptual development, agreement and homogeneity, as well as the promotion of methodological frameworks that encourage and allow an interaction between natural, applied and social sciences, while promoting a wider stakeholder participation"* (Cardona et al., 2010).

While there have been major advances in specialized knowledge of different aspects of disaster risk and disaster context, an associated decline in disaster impacts and losses is not apparent. As this working group has previously expressed, lack of progress may be attributed in part to the nature of the research, which is often unidimensional, often disciplinary-based, not policy prescriptive, and often does not incorporate stakeholders in the research process. These research characteristics manifest themselves in the siloed nature of public policy and actions in development, climate change, and poverty reduction as well.

Integrated disaster research requires transdisciplinary work, in which the true integration of several disciplines can lead to a new discipline with defined characteristics. Transdisciplinarity merges knowledge from natural, social and applied sciences. The results can produce solutions to problems that are not particular to any discipline. Transdisciplinary work involves researchers from diverse disciplines and specialties (including professional and practitioner expertise, and the affected community or representatives), active in the co-production of novel concepts, theory, and methods that lead to new knowledge.

To demonstrate integrated research, it is necessary to assess current advances, programmes and research projects, as well as existing mechanisms for collaborations between researchers and practitioners, so as to have a better understanding of the interactions between them.

Two collaborative research assessments by the AIRDR working group illustrate how AIRDR informs an IRDR approach to disaster risk reduction:

The first assessment reviews current knowledge of disaster risk in order to provide an empirical basis for tailoring research agendas. A preliminary assessment of the landscape of integrated disaster risk research highlighted the limitations of focusing solely on English-language literature, (Gall et al. 2014). With Gall et al (2014) as a methodological template, the AIRDR Guide to Assessing Integrated Research on Disaster Risk (IRDR, 2014a) aims to facilitate a broader and more inclusive systematic review of integrated research on disaster risk. The Guide is designed to promote systematic reviews of local and regional research contributions in other publication outlets and in native languages, for a global synthesis. The Guide documents the methodology in Gall et al (2014) and provides a step-by-step procedure for conducting systematic reviews as a means for sharing and encouraging locally-based assessments using a common protocol. In this way, the collective inputs can be integrated to achieve global synthesis of the state-of-the-art in integrated disaster risk research.

The second assessment is of current advances in the Latin American region, based on existing disaster risk reduction (DRR) programmes and projects (see www.estudiarrd.org). The assessment is designed to support recommendations for the definition of a regional strategy to strengthen the integration of agendas established across the scientific community, Disaster Risk Reduction practitioners, and national authorities and actors, thereby reinforcing current efforts within the region. The assessment identifies programmes related to Disaster Risk Reduction in 70 universities in 19 countries across the LAC region, as well as 104 research projects focusing on different aspects of DRR. This assessment is ongoing, expanding to assess integrated DRR projects and university programmes in other regions that share IRDR goals.

Research and advances in the field still call for a shift in focus from response and recovery towards risk reduction strategies (which is happening slowly), as well as analysis and understanding to avoid creating conditions that increase risk (Lo, et al.). To help countries and communities develop sustainability includes learning from experience, avoiding repeating past mistakes, and identifying the underlying causes of disasters, a task to which other working groups of the IRDR programme are also contributing.

2.2 Advances in the scientific evidence for supporting policy and practice.

Disaster risk reduction strategies require collaborations with scientific data, social science problem-focused research, and real-world stakeholder experiences to achieve more comprehensive understanding. This is transdisciplinary research (Hadorn, 2008), transdisciplinary action, or transdisciplinary action research (Stokols, 2006). Case study 1 illustrates how transdisciplinary research advances science to support policy and practice. Case study 2 exemplifies the benefits of transdisciplinary action research.

Case study 1: Human influences on the Taman Bukit Mewah Landslide

A good example of applied integrated research is the massive landslide that hit the housing area, Taman Bukit Mewah in the hill-land of Bukit Antarabangsa, Selangor, Malaysia, on December 6 2008 at about 3.00am. The pre-dawn disaster occurred on the eastern slope of a granitic hill; just two kilometers northward of the same hill where a landslide had caused the tumble of a condominium block of Highland Towers in December 1993 that resulted in the deaths of 48 residents and again on the same hill in November 2002 about 100 metres away from the Highland Towers, a recurring landslide buried a bungalow house that killed 8 people (Komoo and Lim 2003). The landslide in the year 2008, 109m in width and 120m in length with a run-out of 210m, destroyed 14 bungalow houses, and caused 5 deaths and 14 injuries (PWD 2009). The main road, which was the only access for this hill housing estate, was also damaged and debris ridden, cutting off city access for approximately 5,000 residents. A reported 283 families were directly impacted and about 3,000 occupants were evacuated from the area as a precautionary measure.

The PWD (2009) and Low et al (2012) identified the landslide causal factors as a combination of factors such as: the existence of loose soil from earth-dumping on the slope, which took place during the development of the area; prolonged rainfall during the months of October and November; widening of existing cracks and opening of new tension cracks due to prolonged creep and, lastly, damage of water pipes due to soil creep. The forensic investigation by Lim *et al* (in press) included aerial photograph evidence and site investigations on the anthropogenic dimension of the landslide disaster (Figure 3). In the sequential aerial photograph analysis (Figure 4), they showed the area of vegetation cover cleared since 1966 (4a), initially for plantation. Clearance intensified from 1981 (Figure 4b), until 1985. By 1992 almost the whole area up to the hillcrest was “bald” and had been replaced with housing. This case study illustrated recurrences of landslides as influenced by human intervention in the construction process. The red box in aerial photograph (Figure 4c, 1985) showed a few rows of completed terrace houses on the slope. Subsequently, aerial photography shows that part of the completed housing “disappeared” in 1992 (Figure 4d). An old topographic map and aerial photography (Figure 4a) shows that the natural drainage path was covered or filled up at a later stage. The missing houses, as reflected in a geological report (Suratman, 1993) and landslide investigation report (PWD 2008), were actually damaged in a landslide *circa* 1984. Two rows of houses were demolished in 1985. Eventually the houses in the red box were deserted before completion, due to instability and internal damages. Twenty-eight years later, the 2008 landslide occurred. The runout took exactly the same path as the old landslide reported in 1984 (Suratman 1993; PWD 2008). Forensic site investigation (Lim et al, in press) on the second day after the disaster found the debris on the slope was composed of fill material, boulders, and wood from failed slope retention walls. High water content in soils saw some houses floating and flowing on the debris.

The investigators agreed that the warm and humid tropical climate, and fertile soil had promoted rapid vegetation growth – something which is evidential in vintage photos showing there had been a complete deforestation, as compared with more recent images of full grown forest. The thick forest cover on the slope shown in Figure 3, and the darker-shade areas in Figure 4b, in contrast with white areas in Figure 4a, actually show forest regrowth, but might be mistaken as pristine forest, when it fact they conceal the threat from old landslides or battered land.

This case study demonstrates that forensic work using vintage aerial photographs and site investigations can yield valuable information about the multi-fold root causes of a disaster. The findings also reemphasize the importance of evidence-based analyses incorporating data from a variety of sources and times, to complement primary research and investigations. An additional complexity of the risk in landslide disasters emerged, namely the role of human activity as a major culprit or underlying risk driver. It also cautions landslide modellers, as well as landslide data collectors and aggregators, to differentiate between human-induced and naturally occurring landslides. Similar findings have emerged in other contemporary landslide studies (e.g. Wartman and Grant, 2017).

Figure 3: The scene of the massive landslide in 2008 that destroyed 14 bungalows at Taman Bukit Mewah, Malaysia (Source: The Star, 2013)

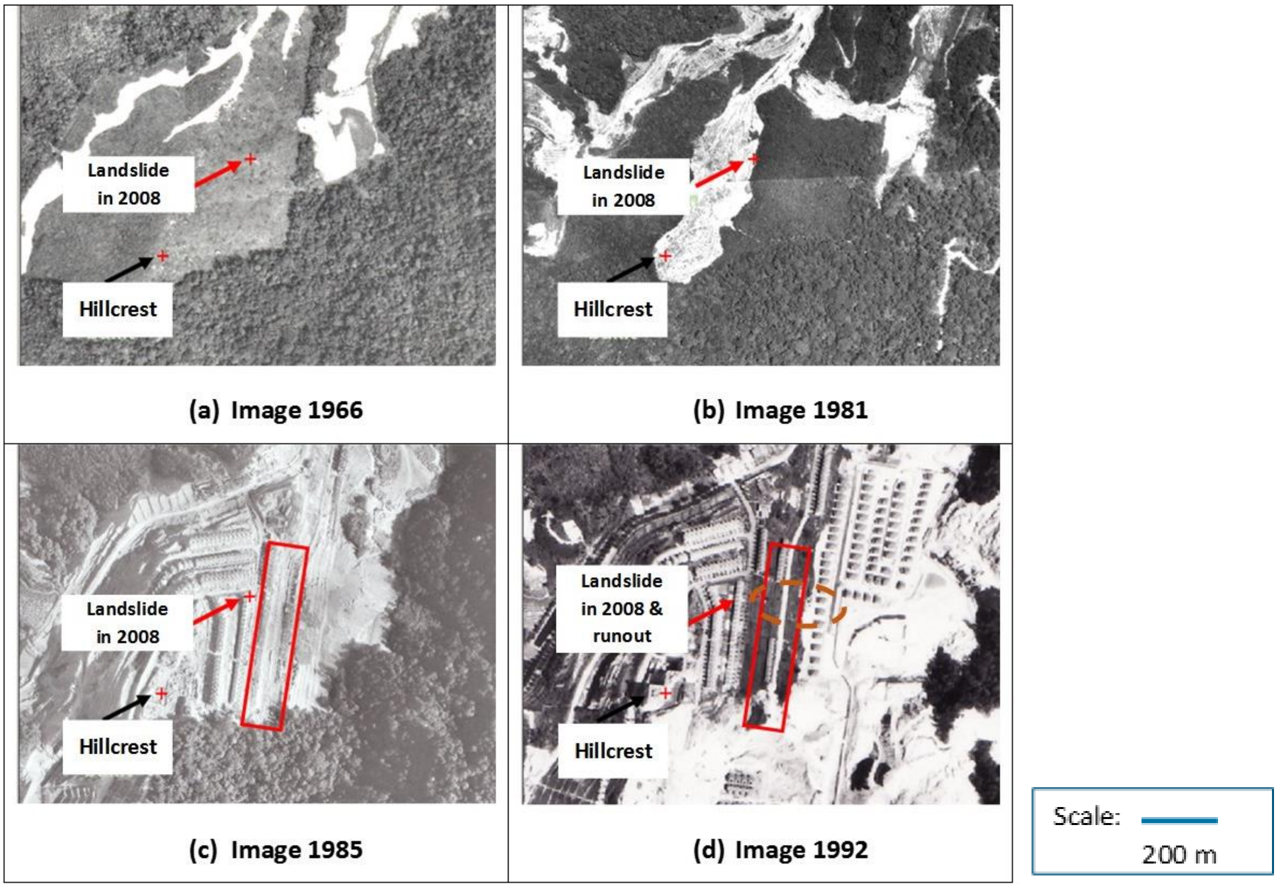

Figure 4: Forensic study of the landslide site from aerial photographs on the historical changes to land cover.

Case Study 2: Risk assessment of compound hazards at Qingping Town, China in 2010

Qingping Town, with a population of about 5900 and area of 300 km2, is in Sichuang Province, China. The town consists of five villages distributed along the Mianyuan River (Figure 5: Qingping Town in 2009). All the villages are situated at the river bank and surrounded by a number of potential debris flow gullies. However, prior to 2008 there were no records of historical debris flow events from those gullies. Geologically, the town sits atop the Qingping-Baiyunshan fault, which is a branch of the Longmenshan fault, stretching through Qingping from Northwest to Southeast. The devastating 2008 Wenchuan earthquake was the result of a rupture on the Longmenshan fault. The earthquake Modified Mercalli intensity was identified as XI (bridges destroyed, few structures remain standing) in the Qingping area. The earthquake triggered a large number of landslides and produced abundant unconsolidated soil on the slope and in the gully, which created favourable conditions for debris flow. Records showed that a gigantic landslide in Wenjia Gully next to Qingping deposited 6×107 m3 of loose material (Xu, 2010).

This case study presents an integrated risk assessment of a disaster event which occurred at Qingping Town in 2010. On August 13 2010, after 230mm of rainfall within 10 hours, 21 debris flows occurred simultaneously and struck Qingping Township (Figure 6). A chain of disasters ensued, beginning with the series of debris flows. Qingping Town suffered three main types of damage during this event. The first was the direct damage from the debris flows, including debris flows in Luojia gully, Dongzi gully, Wawa gully, Linjia gully and Taiyang gully, which directly destroyed or submerged structures. The second was damage due to overflowing water from the partly blocked Mianyuan river. The most severe damage from flooding was at Wenjia gully, where the Mianyuan River was completely blocked by the debris flow and formed a dammed lake. The subsequent dam-breaking flood was responsible for over 30% of the accumulated damage at Qingping Township resulting from the cascade of hazardous events.

Integrated risk assessment of these events must consider all three types of potential hazards posed by the debris flow. In this case, a general risk function (Eq. 1) is proposed:

$$\mathrm{R} = f(D_e, D_h, D_i, D_f) \times \mathrm{V} \qquad \text{(Eq-1)}$$

Where here, D is the total hazard degree, D_e is the hazard caused by the impact force of the debris flow represented by the maximum kinetic energy during the whole debris flow movement process, D_h is the hazard caused by debris flow represented by flow depth, D_i is the inundating hazard of the barrier lake represented by the inundated backwater depth, D_f is the dam-breaking flood hazard represented by the highest water level and velocity of the flooding, and V is the vulnerability of the town, based on land usage data and represented by its economic value. The detailed methodology and calculation of this function (Eq.1) can be found in Cui et al. (2016) and Zou et al. (2016).

The assessment result is presented in Figure 7; the high-risk zone accounts for 33.4% of the total affected area, or 837,000 m2, while the medium-risk zone is 792,000 m2 (31.6%), and the low-risk zone is 875,000 m2 (35.0%). High risk areas are distributed in low altitude areas, which suffered from dam-break flooding and which were at the exit of the debris flow gully and subjected to debris flow impact. On the other hand, high altitude areas are generally within a low risk area, out of reach of flood and debris flows.

After this event, Qingping went through a reconstruction process, which is now complete (Figure 8). Risk assessments became a critical indicator during the design of the new town. Land use was planned based on the assessed risk level. Most of the high-risk region has now changed to farmland to avoid potential human casualties. New roads have been shifted toward higher altitudes to reduce potential damages. Engineering control measures also have been deployed to further control overall disaster risk. This case demonstrates how scientific involvement can benefit local government decision making in the reconstruction of disaster affected areas. This ideal could also be applied to any new town planning in mountainous regions.

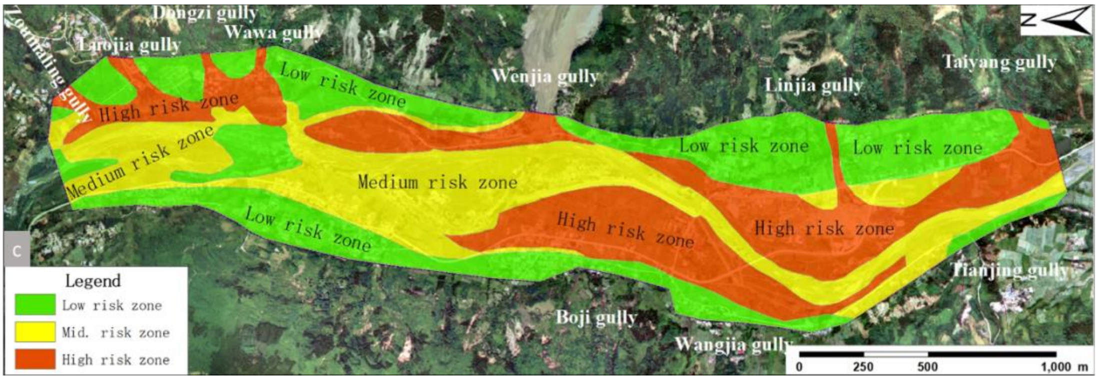

Figure 5: Qingping Town in 2009

Figure 6: The “8.13” Debris flow Event

Figure 7: Risk assessment result of Qingping Town

Figure 8: New Qingping Town (2018)

3 Disaster Loss Data

Disaster reconnaissance and loss data collection are fundamental for a comprehensive assessment of socially, temporal and spatially disaggregated loss data. Risk interpretation with standardized loss data can be used in loss forecasting and historical loss modelling, which in turn provide valuable opportunities to acquire better information about the economic, ecological and social costs of disasters. More rigorous collection of data can better inform policy, practice, and investment. Improving data collection requires a multi-agency, multi-sectoral approach, in order to capture prior experience and the full range of relevant data. This section describes a standard framework and protocols for loss data collection systems to enhanced risk assessments. The disaster loss data frameworks and protocols described here have been tested to accommodate data from multiple agencies, sectors and across geographic scales, to support risk assessment.

3.1 Standards or protocols to reduce uncertainty in the data and SFDRR

In March, 2015, 187 United Nations Member States adopted the Sendai Framework for Disaster Risk Reduction 2015–2030, at the Third United Nations World Conference on Disaster Risk Reduction in Japan (UNISDR 2015). Three other UN landmark agreements linking within the Sendai Framework were reached in 2015 and 2016: the Sustainable Development Goals (SDGs) (United Nations 2015), the Paris Climate Agreement (UNFCC 2015), and the Habitat III New Urban Agenda (United Nations Habitat III 2016). The Sendai Framework has four priorities for action and seven global targets that jointly address local, national, regional and global level disaster risk reduction. To monitor the seven Sendai Framework global targets, the UN General Assembly defined 38 indicators, which UN member states are required to report biannually (Resolution A/71/644, 2 February, 2017).

Disaster loss data can be collected and recorded by multiple sectors - governments, technical experts, DRR and other researchers, the private sector, the general population, volunteers and insurance authorities. However, it is vital to acquire data using standardised terminology, as well as in a standardised format, to enable effective data sharing. Data sharing is enhanced when common data collection protocols are used. Although data sharing is subject to various potential barriers and constraints — such as data ownership, data use provisions, and acknowledgment of data sources — overall data sharing reduces data acquisition costs and time (European Commission, 2015). This section describes elements of a proposed framework for disaster loss and damage data acquisition, shown in Figure 9.

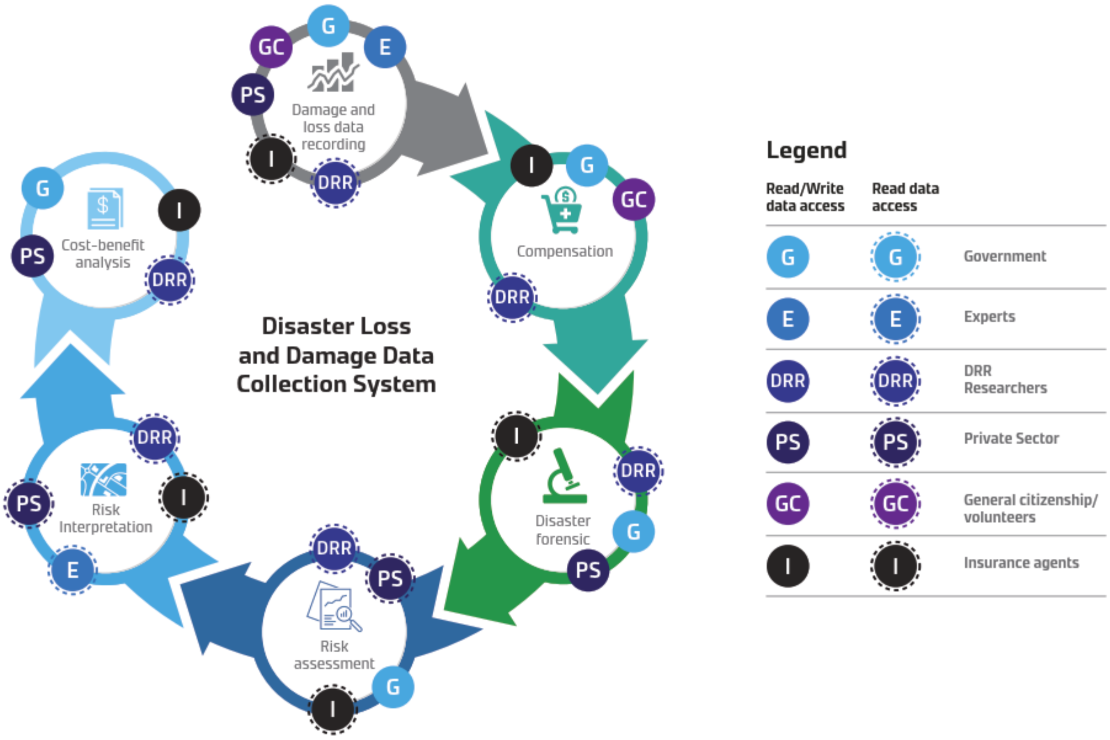

Figure 9: Proposed disaster loss and damage data collection system (Fakhruddin, 2017, modified from De Groeve, 2015)

Damage and loss data recording

Currently, accounting disaster loss records are often gathered from diverse sources, including media, insurance claims, and scientific reports. Public enquiry resources are a primary source of information when establishing a historical baseline for future monitoring. They have in part been used to inform risk investments and can allow forecasting of the average investment needed for recovery per year. Unfortunately, the organisations that are best positioned to record detailed losses—local governments—rarely do so, either because they see little benefit in it, or lack the resources to do it. The lack of either mandates or data collection and management capacity may present barriers to establishing databases.

Compensation data

In many countries, loss data belong to the insurers and are retained as their own records (e.g. data collected following the US cyclones and New Zealand earthquakes). Apart from this, in low- and middle-income countries, compensation comes largely from government resources, humanitarian aid organizations or informal family exchanges (for example, remittances). Insurers are not active in many low- and middle-income countries and thus may not be of relevance for many of the most at-risk global population (GRR Report, 2017).

Disaster forensics

Disaster forensics identify loss drivers by measuring the relative contributions of exposure, vulnerability, coping capacity, mitigation and response to the disaster (JRC, 2015). Disaster forensics require detailed loss information linking important sources of direct and indirect, reversible and irreversible damage and loss to a central database at national level.

Risk assessment

Risk assessment requires damage and loss data to quantify risk. Quantification of disaster losses contribute to evaluating the number of people killed and the damage to buildings, infrastructure and natural resources. The impacts of hazards on infrastructure, people, and society are typically complex to model accurately. Instead, practice shows that it may be more helpful to rely on empirical models or probabilistic modelling using big data such as global, regional and local hydro-meteorological, geo and socio-economic databases, calibrated with historical losses.

Risk interpretation

A major conundrum in risk assessment is the issue of how to convey risk and uncertainty to best inform decision making (Chan and Murray 2017). While opinions are mixed, there is nonetheless a degree of consensus that the level of certainty around risk should be communicated as part of risk information (Fakhruddin, 2017; Fischhoff and Davis, 2014). How people make decisions based on risk information, including the important effects of past experience, has been the subject of significant research (Eiser et al 2012, Gluckman, 2014, IJDRR).

Cost benefit analysis

Cost components, together with financial and non-financial benefits in disaster loss data, are challenging to analyse. According to 2017 UNISDR data, the average estimated loss due to natural hazards globally is $US314 billion per year, perhaps 50% more in the case of recurring disasters such as hurricanes Irma, Jose, Katia and Maria, and the recent Mexico earthquakes (UNISDR, 2017). Such absolute economic assessments underplay the significance of physical impacts on vulnerable and poverty affected households, often the populations hardest hit (e.g. the recent impacts of Cyclone Gita, UNISDR, 2017).

3.2 Achieving synergies by coordinating across loss data stakeholders

The disaster data landscape is complex, though information on loss data is rapidly growing. As noted above, when human, monetary or environmental losses occur as a result of a disaster, extensive loss data are often collected and stored by a variety of organizations; the thoroughness and accuracy of the data vary from country to country and even among local entities. Standardising data is one of the keys to achieving reliable loss estimation, risk assessment and cost benefit analysis for hazards.

The Sendai Framework recognizes this need in its guiding principles: 'Disaster risk reduction requires a multi-hazard approach and inclusive risk-informed decision-making based on the open exchange and dissemination of disaggregated data, including by sex, age and disability, as well as on easily accessible, up-to-date, comprehensible, science-based, non-sensitive risk information….' (Sendai Framework 2015 paragraph 19g). However, assessment processes are challenging, as they require collaboration and participation across multiple sectors, as well as the establishment of mechanisms to share data within and across UN member states, the UN system, and other stakeholders (Chan. nd et al). Some recent products—such as the standard hazard terminology and peril classification for operational use in loss databases (IRDR, 2014b), and standard loss data frameworks (Fakhruddin et al, 2017)—demonstrate ways of linking data stakeholders and creating shared understanding of loss data requirements. The IRDR peril glossary (IRDR, 2014b) provides guidelines for event classification and a unified terminology for operating loss databases only. It is not intended as a comprehensive list of perils, or as a conclusive definitional standard for hazards. The glossary details the classification scheme and hazard definitions used in loss databases, which have been implemented over time in global databases such EM-DAT, NatCatService, and Sigma, as well as in national databases such as DesInventar and SHELDUS.

3.3 Loss data for risk assessment and risk communication

A major conundrum in risk assessment is the issue of how to convey risk and uncertainty to best inform decision making. While opinions are mixed, there is nonetheless a degree of consensus that the level of certainty around risk should be communicated as part of risk information (Fakhruddin, 2017; Fischhoff and Davis, 2014). How people make decisions based on risk information, including the important effects of past experience, has been the subject of significant research (Eiser et al 2012, Gluckman, 2014, IJDRR; Spiegelhalter, 2017). Understanding the risk posed by a hazard and what actions will effectively reduce that risk are critical for informed decision making. Yet risk information is often disseminated with insufficient evaluation and an inadequate understanding of how the information is likely to be interpreted or used (Fischhoff, Brewer and Downs, 2011). Formal and informal assessments of disaster impacts and experiences also influence the interpretation and evaluation of risk mitigation measures.

Case study 3: Rapid damage assessment and decision support.

The contexts for any disaster are complex and dynamic; response processes should be flexible enough to address unforeseen situations without causing social harm or jeopardizing people's lives. A decision support system for rapid damage assessment proved invaluable during the disaster response for the Cyclone Winston in Fiji and Cyclone Gita in Tonga. The system relied on satellite and remote sensing in addition to other sources of information. Fiji's location in the tropical southwest Pacific Ocean makes it vulnerable to tropical cyclones (TC). Since 1980 a total of 42 TCs have hit the country, with more than 300 deaths. The recent TC Winston caused 44 deaths; more than 44 percent of the population was highly impacted, with total estimated damages of around USD 250 million. Tonkin + Taylor International (TTI) conducted rapid disaster mapping within 24 hours of TC Winston's landfall in Fiji. Support for those most vulnerable from cyclone hazards in Fiji benefited from the experience TTI gained assisting the New Zealand Government with the Christchurch earthquake sequence. A GIS web-based platform was set up to facilitate access to factual and interpretative reconnaissance information. This assisted humanitarian aid organisations and UNOCHA to coordinate their response. Key information added to this platform comprised high resolution oblique aerial imagery taken by the New Zealand Defence Force, TTI's on-ground expert, the World Bank, and the Royal Australian Airforce in the days following the cyclone. Regional-scale building damage assessments were undertaken by data analysts in New Zealand within two days of these photographs becoming available. Evacuation centre locations and aid deployment information was also added at the request of aid organisations utilising this information. Other relevant information relating to the cyclone path, storm tide levels and road closure information was also provided (Figure 10).

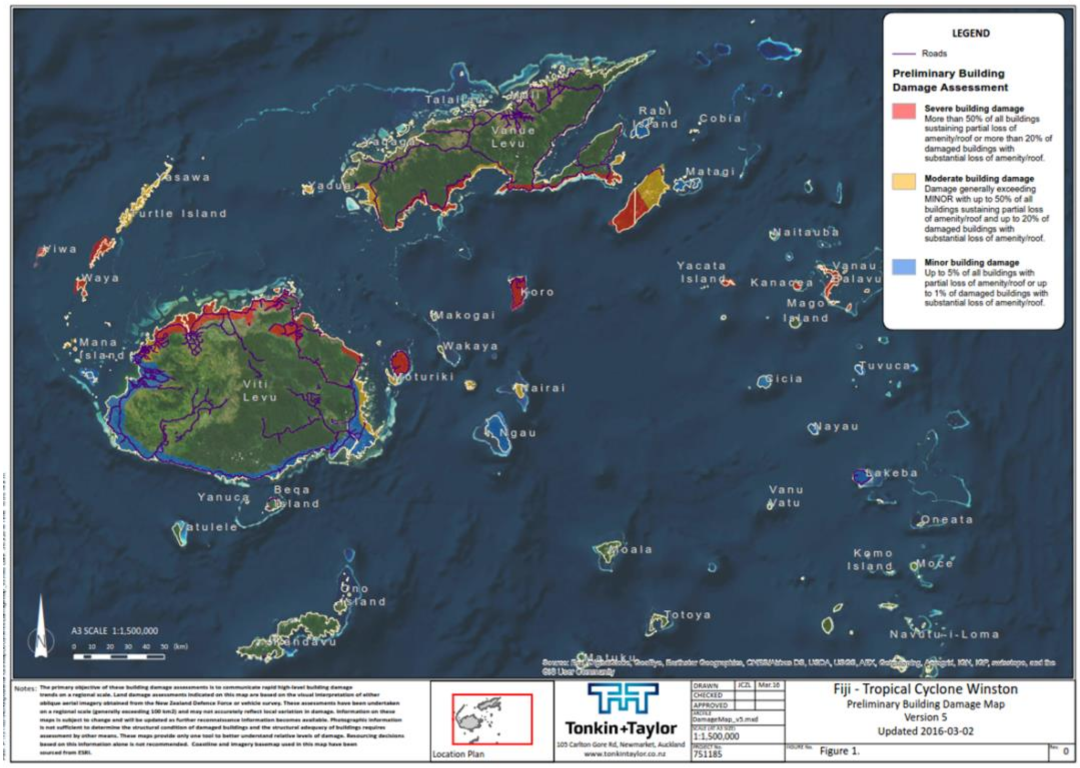

Figure 10: T+TI's Rapid disaster mapping for TC Winston

Comprehensive disaster loss data can produce valuable risk information for decision making authorities. Such data can be used to establish loss trends, as well as to understand the spatial extent of losses, and can be used for developing policies, rapid damage assessment, and disaster recovery. Furthermore, scientific researchers, insurers and other entities benefit from the risk interpretation process (Statistics NZ, 2017). However, the complexities and inconsistencies in dealing with loss information can lead to entirely incorrect calibration. This, in turn, can lead to uncertainty and frustration within affected communities, as was experienced in Christchurch, Canterbury, following the 2011 earthquakes (EQC, 2016).

4 Gaining Insight into Roots Causes of Risk and Risk production—Forensic Investigations of Disasters (FORIN)

> *"The recently adopted Sendai Framework for Disaster Risk Reduction 2015-2030 explicitly recognizes that a range of underlying causes and drivers participate in the social construction of disaster risk. However, in the media, policy discourse and research, disasters are still frequently characterized as unexpected, unforeseeable, overwhelming and fundamentally exogenous events."* (p 5, Oliver-Smith et al 2016).

IRDR aims to enhance societal capacity to address hazards around the world, by informing decisions on actions to reduce their impacts. This includes shifting away from a response-recovery focus toward prevention-mitigation strategies and the integration of disaster risk reduction into development policy and practice. This shift, toward avoiding the social construction of risk, reducing risk from hazards, and building resilience to them, can be enabled by learning systematically from experience.

While disasters such as those following the 2010 earthquake in Haiti, the Great Eastern Japan earthquake and tsunami in March 2011, and Hurricane Harvey in Houston in 2017 are often characterized as natural, or "force majeure," human decisions and actions are root causes of the disastrous consequences triggered by natural hazards in each of these. Shaped by colonial forces that were subsequently exacerbated by economic and political pressures, Haiti was extremely vulnerable at the time of the 2010 earthquake, and generally unaware of and unprepared for earthquakes (Lundahl 2006; Oliver-Smith et al. 2016). While the Great Eastern Japan earthquake and tsunami were the immediate triggers for the Fukushima-Daiichi nuclear power plant accident, siting and other human decisions and actions were root causes of the catastrophic consequences (Srinivasan & Rethinaraj 2013). The unprecedented flooding of Houston, Texas in Hurricane Harvey resulted not only from previously unseen storm behaviour (rainfall) attributable to anthropogenic climate change (van Oldenborgh et al., 2017, 2018), but also from growth in impervious surfaces and other human interventions in the environment (see e.g. Rosenbloom, 2018). As these examples illustrate, disasters are anthropogenic. Understanding their root causes and risk drivers is essential to enabling progress on disaster risk management.

Developed initially from the pressure-and-release model (e.g. Blaikie et al.,1994), forensic investigations of disasters (FORIN) examine how root causes relate to risk drivers, leading to disaster occurrence. FORIN comprises a systematic approach for examining the root causes and dynamics of disaster risks. Forensic investigations of disasters include assessment of (a) triggering events, which may include cascading events (e.g. earthquakes followed by landslides or tsunamis); (b) exposure of social and environmental elements, including not only people and infrastructure, but also means of production, natural resources and wealth); (c) the social and economic structure of exposed communities, their resilience and vulnerabilities; and (d) institutional and governance elements, including legislation, insurance, authority and participation in decision making, and education and research capacity for disaster risk management (Oliver-Smith et al., 2016). To investigate these elements, four research strategies are proposed: retrospective longitudinal (historical) analysis, FORIN disaster scenario building, comparative case studies, and meta-analyses (Oliver-Smith et al., 2016). Each of these strategies recognizes the value of thick description, but also of causal analysis and systematic assessment of commonalities across studies. Fundamentally, FORIN is a transdisciplinary approach that requires multiple methods, disciplines, and participatory research (Hadorn et al., 2008, cf Oliver-Smith et al 2016).

Little progress on learning systematically from disaster risk research was evident under the Hyogo Framework for Action (Oliver-Smith et al., 2017). FORIN provides a strategy for progress, is at the heart of the IRDR scientific programme, and is essential to achieving the goals of the Sendai Framework for Disaster Risk Reduction.

4.1 Forensic Research Methodology and Its Applications

The choice of methods and approaches in forensic disaster investigations is guided by their potential value in achieving the objectives described in Section 3 above. Forensic research may be undertaken following any one or combination of four basic approaches that together provide an overall general guide to research.

The four suggested FORIN research approaches are:

Retrospective longitudinal analysis (RLA), concerned with the temporal development of the processes that have produced disasters in the past. For the 2010 earthquake in Haiti, RLA reveals that some aspects of risk and vulnerability have very deep roots in colonial history (Oliver-Smith et al., 2016).

FORIN disaster scenario building (FDSB), selected on the basis of a known hazard that preludes a possibly inevitable future event that is considered a factor in future disaster (basically looks forward into the future scenarios). Scenario building is a well-known strategy to produce alternative images of how the future might unfold, and is used in a wide variety of situations ranging from commercial ventures to policy and military contexts (Oliver-Smith et al., 2016).

Comparative case analysis—an event-based analysis that seeks to identify underlying causes of disasters by comparing disaster impacts or contexts in different social contexts. An example where comparative study has been useful is the case of Hurricane Luis impacts on the distinct French and Dutch parts of the NE Caribbean island of St Maarten in September 1995. Despite there being more intense winds and rainfall on the French side of the island, damage and loss was considerably less than on the Dutch side. In the case of the Dutch territory the damage was catastrophic. There, direct losses were equivalent to the annual gross domestic product (GDP), whilst indirect losses accounted for a similar amount (Oliver-Smith et al., 2016).

Meta-analysis—an event- or system-based review of the available literature carried out to identify and assess consistent and contrasting findings across diverse studies. The research led by the Study Group on the Disaster Vulnerability of Megacities of the International Geographical Union and the subsequent book "Crucibles of hazards: mega-cities and disasters in transition" (Mitchell, 1999) is informed by a meta-analytical perspective.

5 Risk Interpretation and Action (RIA)

5.1 Individual perceptions and risk behaviour (the RIA framework)

Understanding how people interpret risks and how they choose to act based on their interpretations is vital to reducing disaster risk. This section introduces the risk interpretation and action framework (Eiser et al., 2012) and highlights recent research advances and new opportunities. Risks from natural hazards are shaped by interactions between natural (bio- and geophysical) and human (behavioral and engineering) factors across time, space, and social scales (e.g. Kates, 1971). Further, rather than following idealized models of economic optimization or rationality, decision making under uncertainty depends on people's feelings, experiences, cultural beliefs and values in the context of these interactions (Becker et al., 2017; Eiser et al., 2012; Milch et al. 2017; Sword-Daniels et al., 2016; Chan, et al 2018). Such interactions can increase existing disparities in vulnerabilities, and in access to information and resources for protection and recovery. Importantly, trust moderates the effectiveness of warnings, communications and engagement policies.

Reviewing the RIA framework, Doyle et al. (2014) made three observations: (1) Risk interpretation and action is social and cultural as well, not just psychological; (2) effective communication of risks is relevant for numerous policy domains, especially with regard to the goal of effectively informing individual decision making, but there is an ongoing need to shift from risk communication to risk engagement across these domains; and (3) there is a continued need for collective, multiscale, multi-actor, multi- and transdisciplinary exploration of risk interpretation and action, in addition to the need to further explore risk interpretation and action at the individual, psychological scale. Each of these observations previews themes that have been important in disaster risk research historically, as well as in recent advances.

While social and cultural aspects of risk are and have long been widely recognized, new insights continue to emerge (Chan, et al 2019), even as communications technologies and behaviors are evolving (e.g. Taylor et al., 2018). Ecological models depict concentric social scales of influence on risk interpretation and action, from the proximate influence of family and friends, to larger-scale organizational and institutional influences (Bronfenbrenner, 1977; NASEM, 2018; see also Kates 1971). Ways in which risk interpretation and action are socially and culturally embedded have been highlighted, for example, in research on recent extreme weather events (Taylor et al., 2018). This has shown that social roles can prejudice the assignment of decision making authority, leaving women out (e.g. Luft, 2016), and seeing neighbors evacuate increases the likelihood of deciding to evacuate (e.g. Huang et al., 2016; Lazo et al., 2015). Emerging research tools inform new appreciation of the importance of social networks and social media, reaffirming the central roles of selective attention and motivated reasoning, and illustrating that the collective dynamics of these processes can exacerbate culturally-specific sense making (e.g. Contractor and DeChurch, 2014; Jasny et al., 2015), resulting in increasingly divergent interpretations of, and beliefs about, events.

Engagement is increasingly recognized as the most effective form of communication (Fischhoff, 1995; NASEM 2017). Yet participatory approaches to disaster risk reduction, such as community-based disaster risk reduction and co-production of knowledge are recognized as challenging, while also prerequisite for effective risk action (e.g. Cadag et al., 2017; Delica-Willison & Gaillard, 2012; Pelling, 1998; Renn, 2008; Chan, et al 2018). The inherent irreducibility of the uncertainties and complexity of lived experiences—or *embodied uncertainty* (Sword-Daniels et al 2016)—and the variability and influence of mental models of risk (Bostrom, 2018) exemplify why co-production of knowledge can be both necessary and effective.

Further, uncertainties stem also from the inherent unpredictability of future socio-economic developments, incomplete knowledge about hazards and climate systems, and the limitations of existing models to generate climate and extreme weather projections (Stainforth, 2007), especially with regard to the spatial downscaling required for local planning and policy decisions. While global circulation models (GCMs) may provide credible quantitative estimates of future climate changes at continental or global scales, there are challenges to downscaling the results to support adaptation decisions at regional or local scales (Solomon et al., 2007). Uncertainty is further confounded by the effects of land use changes (Kundzewicz, 2013). In relation to uncertainty due to the transfer of model outputs in time, differentiation must be made between current and future flood loss and damage assessment risks, particularly when considering climate change impacts (Surminski et al., 2012). The risk interpretation and action (RIA) framework complements historical strengths of disciplinary approaches to disaster and hazard research, for example by disaster sociologists (e.g. Quarantelli, 2003; Mileti, 1999; Peek & Mileti 2002; Tierney, 2014), cultural anthropologists (e.g. Oliver-Smith, 2016; Lazrus, 2016), and geographers (e.g. Burton, 2010; Cutter et al. 2008; Kates, 2001; Pelling, 1998; White et al., 2001), in many instances working interdisciplinary (e.g. Oliver-Smith et al., 2016; Tierney et al., 2001). Further integrating emerging psychology and behavioral decision research with these and other sciences promises to enrich both scientific understanding of the roots and evolution of disasters (e.g. Babcicky & Seebauer 2017), as well as the toolkits available to increase resilience and prevent hazards from becoming disasters (e.g. Ismail-Zadeh et al., 2017). For example, insights from such integrative research offer new approaches to communication (Henrich et al., 2017), decision support (Wong-Parodi and Feygina, 2018; Wong-Parodi et al., 2017), planning, and policy (e.g. Milch et al., 2017).

5.2 Impact based early warning systems

Early warning systems (EWSs) are a major element in disaster risk reduction through improved disaster preparedness. Despite considerable advances in predictive technologies, hydro-meteorological and geohazards continue to claim many thousands of lives, wreaking irreparable damage upon homes, businesses and critical infrastructure, and leaving impoverished economies in their destructive wake. IRDR promotes the development of impact-based early warning systems, integrating across organizations that work in this arena, globally.

In recent years, it has become clear that sustained and efficient investment in multi-hazard early warning systems is vital. This is particularly relevant in Least Developed Countries (LDCs) and Small Island Developing States (SIDS). The need to strengthen access to and availability of early warnings is reiterated in the Sendai Framework for Disaster Risk Reduction, the Paris Climate Change Agreements, and the 2030 Agenda for Sustainable Development.

An early warning is the provision of timely and effective information delivered through trusted institutions, to inform those exposed to hazards to take action to avoid or reduce their risk and prepare for effective response. The integration of each element with equal strength is critical for the success of an EWS. One weak element can cause failure of the overall system. (Figure 11).

There is conclusive research evidence regarding what it takes for people to shed their safety perceptions and then take early protective actions (Rogers, 1985). Early warning systems are only as useful as the 'last mile' of successful evacuation and response. People do not immediately respond to early warnings; worldwide, when people receive warnings they first *search* for additional information to *confirm* that they are really at risk (also called "milling"; Mileti and Darlington, 1997). This searching and confirmation is a social phenomenon, which happens regardless of the technology used to warn. It involves talking things over with others and seeking to hear the same warning multiple times from different sources. Warned people turn to friends, relatives, and strangers to determine if they agree that risk is present and if protective actions are warranted. This process—constructing new perceptions of risk out of existing perceptions of safety—adds time before protective actions are taken. it is fundamental to all human beings worldwide, and it is not going to change. Early public warnings work best when they are under mandate from a government that is trusted, which

Figure 11: End-to-end impact based early warning system (Source: Fakhruddin, 2018)

can facilitate and speed the response process (World Bank and UN, 2010). Ignoring this basic human warning element has and will continue to cost lives. Additional research is needed to develop effective warning communications processes for new media. A decision support system incorporating an end-to-end early warning framework could, for example, enable people to visualize the possible scenarios with probabilities of risk, to reduce their vulnerabilities.

5.3 Dealing with uncertainty under climate change

A recent review by UNISDR (2015) reports that in the past 20 years, 90% of disasters were related to weather and climate extremes such as floods, storms, droughts and extreme temperatures. Many lines of evidence point to an increase in frequencies and intensities of such extremes across the world due to climate change (IPCC 2013). Thus, managing the risks from weather and climate extremes is among the five key reasons for concern (IPCC 2014). Therefore investing in early actions and planning vis-à-vis climate change is vital to reduce disaster risk and enhance societal resilience.

One of today's major challenges is, however, how insights and information from climate sciences can inform decisions about societal responses to climate change. An important paradigm preventing major progress in effectively incorporating climate simulations in decision making is the assumption that doing so requires simulating and predicting regional climate change in ever greater detail (Weaver et al. 2013). Recurring statements appear in both the climate science and impact modelling communities that climate projections are too uncertain and that more accurate and high-resolution predictions of regional climate change, and particularly extreme events are required that exceed the capabilities of current climate models (e.g. Palmer 2016, Ummenhofer and Meehl 2017). Thus, the assumption still persists that current climate models are not able to generate the required climate change information with the level of confidence policy and decision makers require. This has led to a severe underutilization of climate models to support decision making (e.g. Barron 2009, Shukla et al. 2009).

Currently available economic decision support tools are potentially able to make use of the uncertainty associated with climate model simulations, by incorporating probability distributions of climate variables across scenarios (Dittrich et al. 2016). While the climate modeling community is concentrating on further improving their models, there are good reasons to overcome this “prediction-based paradigm,”, i.e. the focus one using climate models to predict as precisely as possible specific climate outcomes or threshold exceedances. Alternatively, for DRR purposes it may be informative to treat climate models as exploratory tools for use in *robust decision frameworks*, designed to take into account uncertainty about the future (e.g. uncertainty arising from climate model ensemble spread, climate variability, or different climate scenarios) as pointed out in Weaver et al. (2013).

An alternative to the traditional use of climate simulations in probabilistic approaches is the recently proposed "Tales of future weather" approach (Hazeleger et al. 2015), which suggests that scenarios tailored to a specific region in combination with numerical weather prediction models might offer a more realistic picture of what future weather might look like. This "narrative" approach provides decision makers with a set of possible and plausible future analogues of a specific observed extreme weather event that caused large impacts. Such "narrative approaches" could encourage climate scientists, numerical weather prediction (NWP) experts, local stakeholders and policy makers to jointly develop future storylines for their region of interest, and might also open up interesting avenues for linking disaster forensics with climate change science (Mechler et al. 2018, submitted).

Uncertainty is pervasive in the climate change debate, with the Intergovernmental Panel on Climate Change (IPCC) providing an explicit guide on consistent treatment of uncertainties (Mastrandrea et al. 2010). However, uncertainty is not unique to climate change, but is a multi-dimensional concept that is omnipresent in our society (e.g. uncertainty in economy, geopolitics and health) and there is no agreement in the literature on how best to classify uncertainties. The ways in which individuals, organizations and societies make decisions is affected by uncertainty about future climate and associated risks from climate extremes as well as by the uncertainties regarding how societies will respond to climate change (Dessai et al. 2007).

There are important synergies between large climate model ensembles and economic decision support tools that allow for uncertainty, but the predominance of the prediction-based paradigm places high demands on climate science and modeling, which arguably artificially limit their use for decision making. These obstacles can be circumvented by focusing on robust decision frameworks that are able to incorporate experiments with large model ensembles that capture sets of assumptions about the world, and explore the implications of these varying assumptions (Weaver et al. 2013). In principle, the robust decision framework can be categorized into three main approaches: (a) finding the least vulnerable strategy across scenarios (robust decision making); (b) defining flexible, adjustable strategies (real option analysis); and (c) diversifying adaptation options to reduce overall risk (portfolio analysis) (Dittrich et al. 2016). These approaches can be implemented in decision support tools based on mathematical and statistical methods to quantitatively derive the economic consequences of alternative decisions aimed at achieving a specific goal. The robust decision framework supports the "discovery of implications of a priori knowledge, novel explanations of known facts, or unrealized properties of conjectures" (Bankes, 1993). However, due to their complexity and high computational requirements, economic decision support tools based on the robust decision framework have so far found relatively little application (Watkiss et al. 2015).

In contrast to traditional scenario methods that struggle to address which futures to highlight and how to inform real decisions, robust decision frameworks assess scenarios as cases where a strategy fails to meet decision makers' goals and standards, evaluated against a number of future outcomes, meaning a systematic, computer-aided process of scenario-discovery (Bryant and Lempert 2010). Another important element of robust decision making is the ability to employ climate information with differing levels of uncertainty in the same analysis, and combining this uncertain climate information with uncertain socio-economic information, such as vulnerability (Chan. et al) and exposure (e.g. Thorarinsdottir et al. 2017).

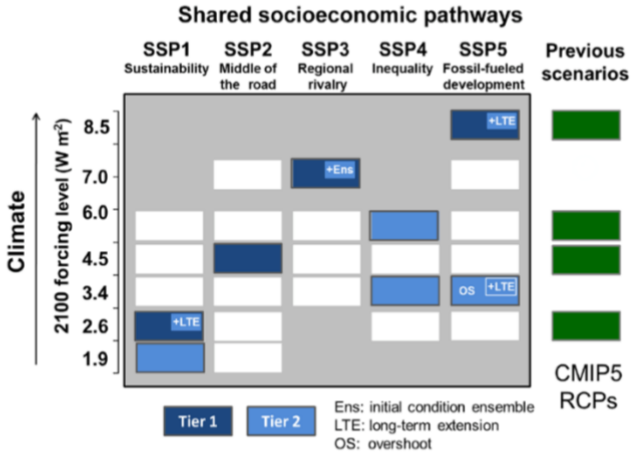

Figure 12: The SSP/RCP matrix showing the pairs of SSP assumptions/RCP radiative forcing that are consistent with one another (white cells). The cells coloured in blue indicate the specific combinations that will be run by CMIP6 participating models.

In the last few years, a set of socio-economic scenarios has been developed to support more integrated analyses of climate change, its impacts, and adaptation and mitigation choices. Five Shared Socioeconomic Pathways (SSPs) span the two-dimensional space of challenges to mitigation and challenges to adaptation, providing consistent qualitative (narratives) and quantitative projections of population, Gross Domestic Product, technology development, international cooperation and many other socio-economic variables. The five SSPs have been named “Sustainability”, “Middle of the Road”, “Fossil-Fuel Development”, “Regional Rivalry” and “Inequality” (Figure 12) and all have different mixes of assumptions leading to different levels of risk from climate change and respective adaptation or mitigation challenges (O’Neill et al. 2014). On the one hand, these scenarios have been used by Integrated Assessment Models to derive new emission pathways consistent with baseline and mitigation choices for each SSP, akin to the Representative Concentration Pathways (RCPs, Van Vuuren et al. 2014). The RCPs have prescribed greenhouse gas concentrations for the CMIP5 simulations of future climate and were based on the socio-economic assumptions described in the IPCC Special Report on Emission Scenarios (Riahi et al. 2016). On the other hand, the variables provided in the SSPs can be used in climate impact studies that want to account for future exposure and vulnerability aspects in conjunction with climate model output. The next generation CMIP6 simulations will be based on a selection of the available SSP-RCP combinations, spanning a range of radiative forcings that is similar with regard to the upper limit to the CMIP5 range (~8.5 Watts/m2) but also includes a trajectory consistent with the 1.5C warming target of the Paris agreement.

As an alternative to scenarios, probabilistic approaches to projecting greenhouse gas concentrations have also been developed recently (Raftery et al., 2017).

6 Communicating Disaster Risk to All-Networks, knowledge flow, and risk reduction expertise

Communication is an essential aspect of effective disaster risk reduction, and is one of the priorities throughout all phases of the disaster cycle. Tools that are able to access and gather information, such as smart phones, tablets and other web-based applications, are an important element that can improve the capacity of communities to cope with disasters (e.g. Sakurai, 2016). New engagement methods which allow the broader appreciation of the difficulties involved when navigating the complexities involved in disaster-related decision processes are also needed to be developed. Such methods that allow the gaps in terminology, resource allocation, and sectoral priorities, all serve to create a more objective and holistic decision making framework amongst stakeholders.

Another important aspect involves the networks and dynamics among the various actors that are necessary to improve community outreach activities. For example, social capital is the way in which social scientists identify relationships and networks among people in the community to community groups and organisations, which in turn may be utilized to expand the capacity of a community to prepare for, respond to, and recover from disasters in the most effective manner possible (Hung, et al.[6]).

6.1 Tools and approaches for community capacity building

The Sendai Framework for Disaster Risk Reduction (SFDRR) stresses the need for innovation, partnership and investment in DRR in order to enhance the role of science and technology for evidence based decision making. The IRDR, with its mandate for integrated and transdisciplinary research, is currently drawing particular attention to capacity building for young professionals, and encourages them to undertake innovative and need-based research (Chan and Murray 2017), which makes science-policy and science-practice linkages stronger. With this approach, it allows the IRDR – Young Scientist Programme, aligned with Sendai Framework, to integrate transdisciplinary research.

The key objectives of the IRDR-Young Scientists Programme are: a) to increase awareness among young scientists about the Sendai Framework and its implementation, while providing opportunities for young scientists to be engaged with the IRDR; and b) to develop, over time, a community of high-quality young professionals that can provide support for countries in their respective national policy development, as well as in field actions related to DRR.

The IRDR Young Scientists Programme began in 2014 with a World Social Sciences Fellows workshop at the New Zealand IRDR ICoE. It is now open for applications twice each year. Since 2016, 115 young researchers from 40 countries have been involved in this programme, among which there are 36 female researchers. In the proposals accepted by IRDR, the focus is on the mechanisms of disaster processes, and the development of a comprehensive understanding of disaster risk, community resilience, and public awareness.

The IRDR has connected young researchers to its network of professionals and practitioners, and has encouraged and recommended them to participate in IRDR-related training programmes. Some IRDR young scientists have published their research results in academic books or special reports in collaboration with IRDR Scientific Committee members (e.g. Sword-Daniels et al., 2016) and IRDR partners such as the UN Major Group for Children & Youth (UNMGCY). About 30 of these young researchers since 2016 have joined training programmes organized by the IRDR ICoEs, such as ICoE-Taipei and ICoE-CCOUC in Hong Kong, and by IRDR partnership with theDigital Belt and Road (DBAR) programme of Chinese Academy of Sciences.

The IRDR Young Scientists Programme is therefore establishing a network for the capacity building of a new generation DRR specialists and researchers. Furthermore, they are not only active in their respective research fields, but they are also contributing to communicating DRR knowledge to local communities.

6.2 A landscape of diverse but unified systems of governance to reduce risk

A critical factor in addressing DRR and climate change adaptation (CCA) is to overcome existing barriers between the complex and diverse set of policies and stakeholders, while building synergies between them. This is related in part to the frequent administrative and political separation of the involved activities. For example, Europe, in particular, provides a uniquely rich arena for exploring transboundary and cross-sectoral cooperation or alignment. Germany, for instance, is organized in a decentralized way which means that responsibilities are shared among different departments. This sees stakeholders dealing with DRR being associated with the Federal Ministry of the Interior, Building and Community, while those involved in CCA activities are, for example, based at the German Environment Agency. However, it is not only the horizontal separations that constitute a challenge, but also vertical ones, as responsibilities are divided among different levels of governance (Marx et al., 2017). Switzerland exemplifies a strongly de-centralised and yet hierarchical system where the Cantonal level has the authority to make decisions in terms of how and when to prioritise and implement actions or measures, funded by and reporting back to Federal level (Abad et al., 2017). France is one of the rare cases in Europe where DRR and CCA fall under the responsibility of the same ministry, the Ministry of Ecological and Solidary Transition. However, the two policy areas are split into separate directorates, with DRR falling under the remit of the General Directorate for Risk Prevention and CCA falling under the remit of the General Directorate for Energy and Climate. This means that in France, the main challenge is not how to avoid policies from diverging, but rather how to ensure there is convergence, which currently remains difficult (Amaratunga et al., 2017a). Opportunities for knowledge-sharing between European states and sectors can, and ought to be, seized and exemplified as a means of unifying (strengthening) international DRR strategies and essentially streamlining efforts, albeit remaining reflective of national priorities.

Fostering and implementing a comprehensive learning culture and mutual understanding among all stakeholders dealing with DRR and CCA (especially where the two intersect) is crucial to overcoming institutional, professional and cultural barriers, and to establishing effective cooperation and communication between the mentioned stakeholders. The *ESPREssO* project (Enhancing Synergies for Disaster Prevention in the European Union), supported by the European Union's Horizon 2020 framework, aimed to contribute to establishing a new strategic vision in Europe's approach to DRR and CCA. To achieve this, three major challenges were identified and addressed by the project consortium: (1) creation of synergies between DRR and CCA sectors at the national and European levels; (2) enhancement of risk management capabilities by better bridging the gap between science and legal/policy issues at local and national levels; (3) improvement and facilitation of more efficient management of trans-boundary crises. In order to gain insight into the many issues surrounding these challenges, an extensive, European-wide forum made up of multi-national stakeholders from all governance levels, including policy, scientific and technical practitioners, was established.

As part of efforts to exploit the knowledge of this forum, use was made of scenario-based exercises, or as they are sometimes referred to in the literature, serious games. These are an effective technique for engaging diverse ranges of stakeholders, such as those involved with DRR and CCA, in order to elicit their insight. Trialled within ESPREssO, these exercises were designed to frame stakeholder interactions and to create an atmosphere of free exchange among all actors involved with DRR and CCA during a simulated crisis or disaster situation. Three versions of these exercises, referred to within the ESPREssO project as *RAMSETE* (Risk Assessment Model Simulation for Emergency Training Exercises), were developed, each dealing with one of the challenges mentioned above: a) policy synergies to boost DRR and CCA integration (RAMSETE I), b) cooperation during transboundary crisis interventions (RAMSETE II), and c) bridging the science-policy interface in a crisis context (RAMSETE III).

Within each exercise, the participants were assigned a "role" to play, usually representing institutions or political bodies. The players would then be assigned to play a role for which their real-life professional or political duties were at least relevant enough for them to contextualize their gameplay choices. The exercises were designed in such a way that they unpicked the key issues arising within each of the three challenges, raised by the stakeholders themselves in initial stages of the ESPREssO project (Amaratunga et al. 2017a; 2017b). In each of the three scenarios, the setting was fictitious, albeit based on realistic examples of "European" nations or areas, where appropriate potential hazards, policies and relationships between the various stakeholders were exemplified in reality.

Gamified elements, such as point scoring and playing-cards, were then used to represent abstractions of these key issues. Gameplay elements reflected such aspects as the scenario region's security, ability to respond to disastrous events, financial resources, and the population's life satisfaction. Players would be limited in their interactions by a ruleset, which was also designed to model real-life issues that in turn served as a way to present these issues to the players, who would be invited to comment on their perception of the issues and the authenticity of the ruleset. Players were encouraged to discuss amongst themselves during the exercise and to supplement the arguments surrounding their decisions by personal experiences and anecdotes. An extensive debriefing session was also held at the end of each exercise. The participants undertaking the exercises evaluated the serious gaming approach as a valuable way to interact with other stakeholders, who cover a wide range of professional backgrounds, while encountering other factors such as different nationalities and language barriers. The exercises triggered discussions among the participants, which were found particularly useful for mutual learning experiences and enhancing interactions, as well as creating synergies between the different stakeholder groups. In particular the opportunity to openly exchange perspectives, discuss and engage with participants with different backgrounds and expertise was highly valued by the participants. The gaming approach, in particular the debriefing sessions that followed the exercise, supported identification of potential links and existing gaps between the different spheres of DRR and CCA. This in turn helped to develop recommendations which were then feed into the ESPREssO project's Guidelines on Risk Management Capabilities (Lauta et al., 2018), as well as a Vision Paper (Zuccaro et al., 2018) on future research strategies in order to better address research priorities highlighted by the Sendai Framework for Disaster Risk Reduction 2015-2030.

Another good example of providing an open forum to allow such exchanges across sectors and disciplines is the Tokyo Resilience Forum, held in November 2017. During this event, it was agreed to formulate guidelines for supporting national platforms for DRR by making the best use of science and technology and to produce a synthesis report on disaster science and technology. Since each country is expected to lead the way for the implementation of this agreement in consideration of their specific conditions, they should develop a mechanism that allows all stakeholders to share information on science and technology for DRR in their own language. With this information infrastructure, the national platform of each country should then review the status and issues of the current DRR efforts that they have implemented based on scientific knowledge. The national platform would then discuss how DRR should be carried out for the country, and design practical measures for it to be implemented from a holistic viewpoint. This series of actions that was taken up by the national platform of each country is called "Synthesis" as a whole, and we propose that Synthesis should be promoted under international cooperation.

6.3 Community outreach activities

As noted above, bottom-up approaches are an effective way to reach the wider community, with participatory processes allowing organisations to reach out to the general population. The quality of social networks can be addressed through social capital, which is composed of 3 elements: bonding, bridging, and linking social capital (see also Kwok et al., 2016). Bonding social capital is the relationship among people, between individuals in their communities. Bridging social capital is the relationship between people and community groups. Linking social capital is the formal relationship among people in the communities that is formed with organisations, including schools, non-government organisations, and government organisations (Nakagawa, 2004; Clay, 2016; Aldrich, 2012)

Neighbourhood-based programmes and projects can more efficiently reach community members, especially vulnerable sections of the population (Kwok et al., 2018). Vulnerable people in social networks could include those who have less access to information or people, who are minorities in the communities which have smaller or limited network. Being vulnerable in social networks results from weak social capital. Having a stronger bonding social capital therefore helps the vulnerable to response to events. For example, in the event of hurricane Katrina, the Vietnamese community of New Orleans developed strong bonding social capital with Vietnamese-Americans. They experienced a better recovery process and were able to reach out to offer aid quickly by their connection among the groups (Aldrich, 2017).

Higher social trust shows a strong linking social capital among governments and a community's members. The strong networks can also lead to better public education, including improving climate change and risk knowledge in communities {United Nations Office for Disaster Risk Reduction, 2013). In communities with a high social trust, people tend to panic less in the event of crisis as they trust their government. This is a sign of a strong linking social capital (Svendsen, 2014).

Developing partnerships with local universities is an efficient way to improve transdisciplinary research. Universities could be a transition among a community's members to local and national government (Wellington Region Civil Defence Emergency Management, 2012; Greenovate Boston, 2014). There is also a greater diversity in the body of knowledge arising from having various actors within a participatory process. This has the potential to lead to an improvement in DDR.

7 Recommendations and Conclusion

Understanding decision making in complex and changing risk contexts

Understanding risk is still high on the agenda for SFDRR and critical in integrating across global agreements. Integrated research can be leveraged by utilizing the increasingly rich but still disparate risk and loss datasets that exist, to enable robust scientific analysis of risk and inform solutions that are applicable at various scales. For example, using emerging sciences and new data to build on existing early warning systems is critical. Improvements in communicating early warning information and forecasts, integrating traditional knowledge into warning information, and using machine learning and other computational strategies to integrate across increasingly detailed and diverse data on hazards and disasters can help inform better decisions.

Understanding risk reduction beyond early warning systems is also important. Informing development by taking into account accumulated risk and everyday risk is key. Science that analyses the linkages in disasters—especially with respect to time and scale—is critical to address the challenges. Integrated scientific knowledge provides some answers.

It is important to take into account that the IRDR mission is “to develop trans-disciplinary, multi-sectoral alliances for in-depth, practical disaster risk reduction research studies, and to implement effective, evidence-based disaster risk policies and practices” (ICSU-LAC, 2010).

To accomplish this task it is necessary to support and facilitate the linkages between scientific and academic communities and decision making. Researchers cannot accomplish this on their own. Integration means including practitioners and communities actively, not merely as spectators of the scientific process, but as co-creators.

Other sources of scientific knowledge need to be considered, including the variety of contexts where research on the topic is carried out, which at least in the LAC region can be within the framework of consultations or through scientific or non-academic initiatives. The inclusion of stakeholders who demand specific applications can change the research process and how it is approached.

Periodic assessments of integrated research are essential to identify the gaps that remain for the scientific community to address in order to implement the Sendai Framework priorities.

Loss Data Standardization

Undoubtedly, establishing a comprehensive national standardized loss data collection and management system is complex due to the multi-sectoral, multi-layered requirements that cross the public and private sectors. However, the value of such systems is now well proven and of benefit for comparing impacts and losses between UN member states globally.

Challenges remain in the ability to convert disaster data to useful, usable and used knowledge that will in turn deliver a reliable evidence base to inform policy and practice to reduce impacts. Disaster data are unlikely to be complete because of their complexity. For this reason, there is also a need for ethical statistical approaches, including Bayesian hierarchical modelling and other techniques. A key consideration will be resource mobilisation for improvement of data collection, recording and reporting at all levels. This will require appropriate levels of investment in building local and regional data collection capacity and, consequently, supporting IT infrastructure.

Gaining Insight into Roots Causes of Risk and Risk production

The social roots of both disasters and climate change suggest an additional application of the FORIN perspective for DRR and climate change adaptation (CCA). However, rather than a focus on “extreme events” in a physical sense, the central concern should be on “high impact events and contexts”, where analysis of the social conditioning factors associated with risk should be a priority. In effect, an “extreme” event is not one where there is the greatest discharge of physical energy, but, rather, one where there is more associated damage and loss.

Risk interpretation and early warning system

For people to make “sustainable, integrated or holistic decision making” decisions, the capacity to generate forecasts with sufficient lead-time of an acceptable degree is essentially based on an end-to-end early warning framework. Research and development (RD) advancements in hazards forecasting using ensemble methods have been widely used for operational forecasting. Either simple, weighted, or selective ensemble mean forecasts tend to have smaller errors than single model–based forecasts. Despite these notable advances in forecasting, it is clear that early warnings are not helpful unless they reach the people who need to act, provide information about potential disaster impacts, and inform action. To ensure effective preparation and effective response to early warnings, the information needs to be comprehensible, relevant, actionable, and trusted by warning recipients. Clear interpretation and translation of scientific information regarding hazard processes and outcomes as well as protective actions is essential. As is the communication of uncertainty in science, or the margin for error to be accurately and objectively communicated, so that cascading decisions made by the end users/ authorities can understand to which degree the scientific input has impacted on decisions made “higher up” or elsewhere”. Ultimately, forecast and warning systems that address users’ needs and expectations are most likely to enable people to visualize hazards, better understand their vulnerability, and ultimately reduce their vulnerability and risk.

Establishing continuity in capacity building and demonstration projects

Continuity in capacity building and demonstration projects is essential. This can be achieved where capacity for disaster risk reduction is not externally driven, but draws on regional, country, or community initiatives and resources. Multinational capacity-based initiatives would require long-term programmes to develop capacity-enabling environments; capacity for risk mapping, monitoring, early warning and information dissemination; capacity for formulating and implementing disaster reduction policies backed by appropriate legal and monitoring frameworks; mechanisms for mainstreaming disaster reduction into development programmes; and investigating and implementing innovative capacity-building schemes, for example, learning from past success stories.

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