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ARTICLE

Thirty Years of Science, Technology, and Academia in Disaster Risk Reduction and Emerging Responsibilities

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Abstract The 1990 initiation of the International Decade for Natural Disaster Reduction marked its 30th year in 2019. The three decades since then have seen significant developments in science and technology and their incorporation into the decision making in the field of disaster risk reduction. The disasters that have occurred during that time have enhanced the importance of the field, and new research and innovations have evolved. This article summarizes this evolution through the review of specific milestones. While the Sendai Framework for Disaster Risk Reduction 2015–2030 provides opportunities for synergies with the sustainable development agenda, the science and technology communities have also changed their roles from advisory to co-designing and co-delivering solutions. Higher education plays an important role in developing new generations of professionals, and the role of thematic incubation in higher education institutions is highlighted along with the development of the professional society in disaster risk reduction. The evolution from Society 4.0 (information age) to Society 5.0 will see an enhanced role of the technology-driven approach in disaster risk reduction, while traditional knowledge and indigenous technologies still remain valid for society. Scientists and science communities need to be more sensitive to changing the "last mile" concept to "first mile" thinking with respect to the users' needs and perspectives.

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1 Evolution of the Disaster Field and Science and Technology

The year 2019 marked the 30th year of structured approaches to disaster risk reduction. This article reviews the historical evolution of science and technology and its impacts, and the evolution in disaster regimes during this time, and discusses some of the future potentials. The year 1990 was a landmark year for disaster risk reduction, when the International Decade for Natural Disaster Reduction (IDNDR, 1990–1999) came into existence with the approval from the United Nations member states. However, its root goes back to 1984, when Frank Press, the President of the National Academy of Sciences of the United States at that time, stated at the 8th World Conference on Earthquake Engineering in San Francisco: "I believe there is great need, and much support can be found, to establish an International Decade of Hazard Reduction. This special initiative would see all nations joining forces to reduce the consequences of natural hazards" (UN 1993).

This led to the UN General Assembly resolution in 1987, and the establishment in 1990 of the first decade of disaster reduction. In his 1984 remarks, Frank Press identified "hazard reduction," an idea that later changed to disaster reduction (as the international decade name states), and then to risk reduction and resilience building from 2000 onwards. Science, technology, and engineering played a key role in influencing the decision to establish the international natural disaster reduction decade.

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The Scientific and Technical Committee (STC) of the IDNDR was established in 1991. In 1993, a formal meeting was held by the STC to bring forward the science-based disaster risk reduction agenda (UN 1993). At that time, since UN IDNDR did not have country presence, the science and technology focal persons from different countries were engaged to discuss and promote the concept of disaster reduction with their respective governments. In 1993, the third committee meeting on national programs and projects and plans for strengthening and building national capabilities was held. The IDNDR Secretariat introduced document IDNDR/STC/1992/3, which summarized the implementation status of national disaster mitigation programs on the basis of information submitted by National Committees and Focal Points. Presentations on IDNDR country programs and progress in disaster mitigation activities at the national level were made by representatives of IDNDR committees from Australia, China, Colombia, Costa Rica, Jamaica, Japan, Spain, Switzerland, Tunisia, and the United States; a STC member reported on IDNDR developments in Africa. The information provided demonstrated the increasing number and significance of disaster mitigation activities initiated or accelerated as a result of the IDNDR. The representatives acknowledged, however, that weaknesses coexisted with strengths in the national capabilities for implementing disaster reduction strategies. Altogether these presentations indicated the planning work done by the STC, particularly with respect to targets, programs, suggestions, and guidelines for nations (UN 1993).

Some issues and challenges that were identified at the meeting in 1993 were:

1. the importance of obtaining the highest political commitment to disaster reduction, in order to raise the relative priority of disaster mitigation in government investment policies, and help reorient expenditure in a way that would take into account disaster vulnerability;
2. the need for more information material on the potential and benefits of disaster prevention and support for public education and awareness campaigns in vulnerable countries;
3. the importance of training and exchange of staff between countries in need of such expertise and those countries more advanced in disaster reduction practices;
4. the need to complete risk-mapping for the major hazards in each country or community in a way accessible to policymakers and administrators;
5. that in vulnerable small or island countries, even micro-assistance projects that require limited resources could have large benefits;
6. the importance of increasing the priority level of disaster reduction projects in country requests for bilateral or multilateral development assistance, as indicated by the General Assembly when proclaiming the IDNDR;
7. the need to assign IDNDR responsibility to deal with already existing disaster management or public entities in different countries (UN 1993).

A close look at these challenges indicates that many of them still exist, even after 30 years of intense advocacy for science-based disaster risk reduction and decision making. In 1994, the First World Conference on Disaster Reduction was held in Yokohama, Japan, and formulated the Yokohama Strategy and Plan of Action for a Safer World (UN 1994). That document emphasized the role of science and technology in the form of more accessible technology, a focus on early warning systems, enhanced capacities among different countries to generate new science, as well as using existing science, and so on. The role of low-cost, appropriate technology is mentioned with higher priorities and importance. Two other key points mentioned in the document are: (1) the importance of local and traditional knowledge and its proper validation and acknowledgment; and (2) the need to expand the scope of science and technology to natural hazard induced technological disasters (NATECH). In 1995, the world witnessed one of many major disasters to come, the Great Hanshin Awaji Earthquake in Japan, which shifted the focus of disaster reduction significantly, with calls for strong multidisciplinary collaboration to address disaster risks. The same need was also felt in the post-disaster recovery of the 1999 Turkey and Taiwan earthquakes.

While the IDNDR was formed, it was associated with the Department of Humanitarian Affairs (DHA), which in 1998 was restructured as the Office for the Coordination of Humanitarian Affairs (OCHA). At the end of the decade declaration (UN 1999), the Secretary General called for enhanced actions on disaster risk reduction in the coming decades, the Chair of the IDNDR Scientific and Technical Committee stressed the need to integrate disaster prevention and mitigation into overall economic planning and emphasized that the distinct nature of disaster prevention needed to be preserved. This paved the path for the establishment of the United Nations International Strategy for Disaster Reduction (UNISDR) in 2000 as an interagency secretariat for disaster reduction (Fig. 1).

While the initial years of the UNISDR were spent to formulate new strategies, national focal points, national disaster risk management plans, and so on, the 2004 Indian Ocean Tsunami again highlighted the importance of early warning and bringing technology to people. In 2005, the Second World Conference on Disaster Reduction was held

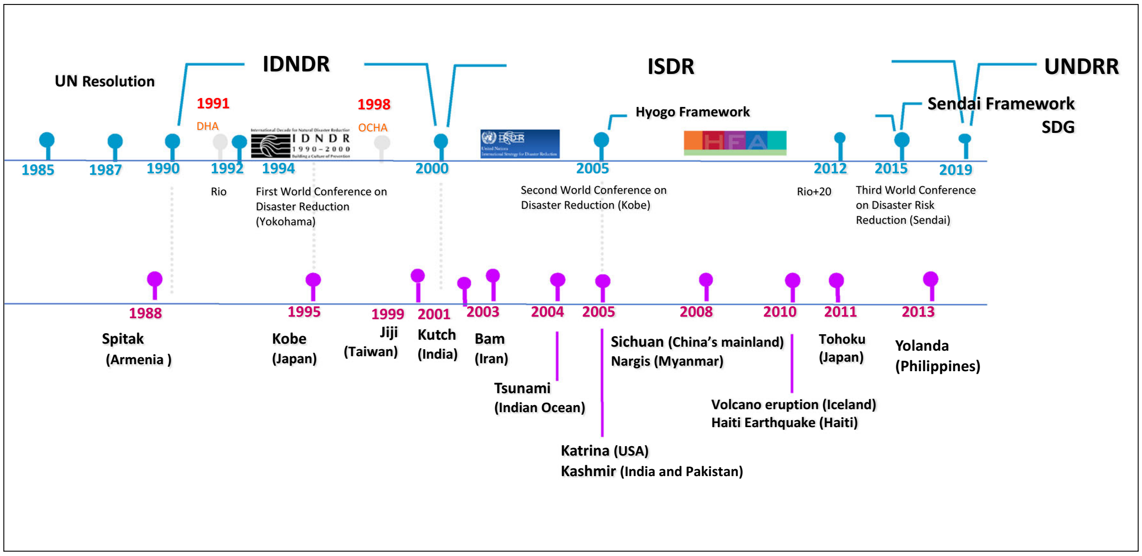

Fig. 1 Evolution of the disaster risk reduction (DRR) field and selected major disasters, 1985–2019. DHA—Department of Humanitarian Affairs; OCHA—Office for the Coordination of Humanitarian Affairs

in Kobe, Japan, and the Hyogo Framework for Action 2005–2015 (HFA) was adopted as the first disaster framework to be implemented by UN member states (UN 2005). While the role of science and technology was mentioned in all five priorities of the framework, it is explicitly mentioned in Priority 2, "Identify, assess and monitor disaster risks and enhance early warning," and Priority 3, "Use knowledge, innovation and education to build a culture of safety and resilience at all levels." National focal points have become the key to implementing, monitoring, and reporting the progress of the Hyogo Framework, and the science and technology communities in respective countries play crucial roles in the reporting system. The Hyogo Framework explicitly mentioned the need to "Strengthen the technical and scientific capacity to develop and apply methodologies, studies and models to assess vulnerabilities to and the impact of geological, weather, water and climate-related hazards, including the improvement of regional monitoring capacities and assessments" (UNISDR 2005, p. 10). During this time, the Global Science and Technology Advisory Group (G-STAG) was formed, which promoted and advised science-based decision and policy making in different countries. Science and technology academia has been recognized as a strong stakeholder group in different regions, as well as globally.

During the 2005–2015 period of the Hyogo Framawork, the world experienced a number of disasters—2005 Hurricane Katrina (United States), 2005 Kashmir Earthquake (India and Pakistan), 2008 Cyclone Nargis (Myanmar) and Sichuan Earthquake (China's mainland), 2010 Haiti Earthquake, 2011 East Japan (Tohoku) Earthquake and Tsunami, 2013 typhoon Yolanda (Philippines), and so on. The 2011 East Japan earthquake, tsunami, and nuclear accident pointed to the complexity of risks and the need for holistic, science-based risk reduction strategies, which led to the Sendai Framework for Disaster Risk Reduction 2015–2030 (UN 2015).

2 Post-Sendai Developments

Atisi-Selma et al. (2016) and Shaw et al. (2016) described and analyzed the key achievements of the Hyogo Framework, and its evolution to the Sendai Framework of Disaster Risk Reduction 2015–2030. The Sendai Framework (UN 2015) aligns with global frameworks like the Sustainable Development goals (SDGs) and the Paris Agreement, and thus the development and disaster nexus becomes crucial.

In this context, the International Disaster Risk Conference (IDRC) Davos meeting of 2014 analyzed and presented key issues on the current status of science and technology in disaster risk reduction (IDRC 2014). The conference emphasized the need for a shift to the "science of how" from a "science of what," so necessary skills and knowledge bases are properly utilized and meet the "last mile" challenge of risk reduction. The 2015 Tokyo Conference on the International Study for Disaster Risk Reduction and Resilience called on policymakers to empower their national disaster risk reduction (DRR) platforms through greater engagement with science and technology (Shaw et al.2016). The Tokyo Statement outcome document of 2015 specified that governments need to empower national platforms so that they can practice evidence-based disaster risk reduction for sustainable development (SCJ 2015).

There are a number of references to science and technology in the Sendai Framework. Paragraph 36(b) requests:

> Academia, scientific and research entities and networks to: focus on the disaster risk factors and scenarios, including emerging disaster risks, in the medium and long term; increase research for regional, national and local application; support action by local communities and authorities; and support the interface between policy and science for decision-making (UN 2015).

More specifically, Paragraph 25(g) states:

> Enhance the scientific and technical work on disaster risk reduction and its mobilization through the coordination of existing networks and scientific research institutions at all levels and all regions with the support of the UNISDR Scientific and Technical Advisory Group in order to: strengthen the evidence-base in support of the implementation of this framework; promote scientific research of disaster risk patterns, causes and effects; disseminate risk information with the best use of geospatial information technology; provide guidance on methodologies and standards for risk assessments, disaster risk modeling and the use of data; identify research and technology gaps and set recommendations for research priority areas in disaster risk reduction; promote and support the availability and application of science and technology to decision-making; contribute to the update of the 2009 UNISDR Terminology on Disaster Risk Reduction; use post-disaster reviews as opportunities to enhance learning and public policy; and disseminate studies (UN 2015).

After Sendai, the first Science and Technology Conference on the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 was held in Geneva in 2016, and a global science and technology roadmap was adopted to implement the Sendai Framework. The Science and Technology Conference achieved two main outcomes: (1) initiating the UNISDR Science and Technology Partnership for the implementation of the Sendai Framework; and (2) generating discussion and agreement regarding the content and endorsement process of the UNISDR Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (Aitsi-Selma et al. 2016). The Secretary-General of the United Nations, in his report to the General Assembly in 2018 emphasized that: "To support the implementation of the Sendai Framework Science and Technology Roadmap, the UNISDR Global Science and Technology Advisory Group has been enhanced in terms of its scope and resources. This includes the establishment of a Science and Technology Partnership and regional Science and Technology Advisory Groups."

The UNISDR Global Science and Technology Advisory Group (G-STAG) undertook the contextualization and revision of the Roadmap in collaboration with other science and technology partners. The purpose was to enhance the relevance of the Roadmap by developing better coherence with other agreements in the 2030 agenda, like the SDGs, the Paris Agreement, and the New Urban agenda, and to link the Roadmap to the Sendai monitoring processes using online platforms. The process started with a discussion in the G-STAG in August 2018 and then a Science and Technology Partnership event in Chengdu, China, 16–17 October 2018. It also incorporates the insights and recommendations from the Science Council of Japan's Tokyo Statement 2017, published following the Global Forum on Science and Technology for Disaster Resilience, held in Tokyo, 23–25 November 2017. The contextualization of the Roadmap was also discussed in the regional workshop on strengthening, empowering, and mobilizing youth and young professionals in Jakarta, Indonesia, 6–9 November 2018. The revised Roadmap was approved at the Geneva Science Policy Forum in May 2019 (Table 1).

The revised Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 includes four expected outcomes and 58 actions under four Priorities for Action of the Sendai Framework. It is expected that the implementation of the Roadmap needs collaboration, cooperation, and commitments from all sectors of societies, including science and technology partnerships, national and local governments, private sectors, civil society, media, and other stakeholders. This can be considered as an overall advocacy tool, and partners/networks would be encouraged to make voluntary commitments and detail means of implementation.

In another significant post-Sendai development, regional Science and Technology Advisory Groups (STAGs) have been formed in some regions, like Asia, the Arab states, Europe, and America. The regional STAG has a specific role to advance the science agenda of the region and link it to the regional platform process. The regional STAGs have also been proactive in enhancing country-based policy advocacy in several cases. Asia's regional STAG was formed in 2015, immediately after Sendai, and is considered one of the leading STAGs, with a specific plan of actions (Shaw et al. 2016). Every two years, the Asia regional STAG organizes the Asia Science and Technology Conference on Disaster Risk Reduction (ASTCDRR),

Table 1 Example of the revised Science and Technology Roadmap with four outcomes under Sendai Framework Priority 1

The Science and Technology Roadmap for the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030				
Total Number of Actions: 58 Priority 1: 21 Priority 2: 14 Priority 3: 11 Priority 4: 12	Outcome 1: Assess and Update Data and Knowledge [State of data, scientific, local and indigenous knowledge and technical expertise are assessed, updated and available on spectrum of Sendai hazards]	Outcome 2: Dissemination [Scientific evidence is synthesized, produced and disseminated in a timely and accessible manner that responds to the knowledge needs of policymakers and practitioners]	Outcome 3: Monitoring and Review [Scientific data and information support are used in monitoring and reviewing progress towards disaster risk reduction and resilience building]	Outcome 4: Capacity building [Better capacity in all sectors and countries to access, understand and use scientific information for better informed decision making]
Priority for Action 1. Understanding disaster risk [Total number of actions: 21 (8 + 4 + 3 + 6)]	1.1.1 Promote integrated and multi- disciplinary research 1.1.2 Conduct solution-driven research at all levels that involves the users in the earliest stages 1.1.3 Establish/link existing and update/maintain global databases 1.1.4 Develop methods, models, scenarios and tools 1.1.5 Integrate risk assessments across sectors 1.1.6 Promote scientific focus on disaster risk root causes, emerging risks and public health threats, insurance and social protection and safety nets 1.1.7 Analyze ethics of scientific input 1.1.8 Adopt a multi-hazard approach that integrates lessons learned, including trans-boundary, biological and technological and Natech hazards	1.2.1 Develop evidence-based research on effective dissemination strategies for informed decision and policy-making 1.2.2 Promote access to data, information and technology 1.2.3 Integrate traditional, indigenous and local knowledge and practices 1.2.4 Develop partnerships between all science and technology and DRR stakeholders, and integrate gender equality	1.3.1 Link science and technology progress to Sendai monitoring indicators, and report using online voluntary commitment system 1.3.2 Promote coherence in data collection and Monitoring and Evaluation indicators with SDGs and Paris Agreement 1.3.3 Develop a liaison group between the DRR community and the major global assessments, such as IPCC 6th Assessment Report and other related assessment	1.4.1 Build national and local capacities for the design, implementation and improvement of DRR plans 1.4.2 Promote inclusiveness, interdisciplinary, and inter- generational participatory approaches 1.4.3 Develop expertise and personnel to use data, information and technology 1.4.4 Promote the development and use of standards and protocols, including certifications 1.4.5 Utilize knowledge resources of science and technology community for effective education programs on disaster risk reduction for scientists, practitioners and communities 1.4.6 Promote systems approaches in understanding disaster for better informed decision

Source Adopted from UNDRR (2019b)

which brings together diverse stakeholders including scientists, academia, governments, civil society, media, private sectors, and UN agencies. The conference reviews the progress and status of science and technology, and makes a commitment for the next two years, which is linked to the regional ministerial conference. This mechanism, along with the Sendai Online Voluntary Commitment (UN 2019) helps in understanding the status and progress of science and technology in the region.

3 Evolution of Disaster Risk Reduction Concepts and the Increasing Importance of Science and Technology

Over the last 30 years, the DRR concept has evolved significantly. There are some commonalities of the concept variants. However, some new concepts are emerging. In the early 1990s, the focus of the IDNDR was to enhance awareness of pre-disaster preparedness measures compared to post-disaster response. The development of legal frameworks was one of the key emphases, and the role of science and technology was mainly to understand risk through risk assessments. Emphasizing the concept of “risk

Fig. 2 Evolution of the risk concept to living with uncertainty. *Source* Adopted from UNDRR (2019a)

reduction" was the key target of the early 2000s, which later changed to resilience building. The role of science and technology also changed from understanding risk to enhancing resilience. The concept of resilience has also evolved over time. After Sendai, climate risk appeared strongly, and holistic risk assessment under an uncertain future has been considered as the "new normal." "Living with risk" has changed to "living with uncertainty" (Fig. 2).

The Global Risk Report 2019 of the World Economic Forum, Davos (WEF 2019) provides an analysis of 10 years of risk priorities in terms of likelihood and impacts. It shows that from 2011 onward, trends of environmental risks like disasters, climate change, and extreme weather have increased, both in terms of likelihood and impacts. This issue calls special attention to the science and technology community, where disaster risks need to be considered in conjunction with other geopolitical, societal, and technological risks, and a systemic risk approach becomes more important.

There has been a parallel evolution of the climate change field with the Intergovernmental Panel on Climate Change (IPCC) focus on the science-policy nexus. Established in 1988, the IPCC has been very effective in science-based policy making through detailed assessment reports. So far, five reports have been published, and currently, the sixth assessment report is being undertaken. A series of specific publications like the SREX report (IPCC 2012) and the 1.5 °C report (IPCC 2018) have also come out and bring forward critical climate risk issues that have a strong connection to disaster risk reduction. Synergies of disaster risk reduction (DRR) and climate change adaptation (CCA) have been much talked about, and technology plays an important role there. Adaptation technology in different sectors like health, agriculture, and water brings new innovation in the DRR technologies as well.

4 Defining and Redefining Science and Technology in the Context of Disaster Risk Reduction

In the ever-changing and dynamic evolution of science and technology, it is important to define and redefine these fields. While the natural and social sciences started as traditional disciplines, the increasing role of geography, economics, architecture, planning, art, and culture and other humanities is noticeable in the field of disaster risk reduction. In terms of engineering, while the field started mainly from civil engineering contributing significantly to the solutions for DRR, currently broader aspects of environmental or infrastructure and society-based engineering are playing critical roles in DRR. The role of the health sciences is also becoming increasingly important. New interdisciplinary subjects like sustainability science, survivability science, and disaster nursing are drawing increasing attention. Broader aspects of environmental management cover different aspects of science and technology-related issues.

Kameda et al. (2009) categorized technologies into three aspects, which are still relevant. He defined "technology" as "a set of rational means and knowledge pertinent to realizing specific objectives that have solid logical bases and stability" (Kameda 2009, p. 208). Although conventionally, technology relates more to engineering products, implementation technology is related to the implementation process. Thus, the meaning of technology for disaster risk reduction can be broadened to both products and processes. Through the landmark project Disaster

Reduction Hyperbase (DRH), (Kameda 2009) described technology in three categories, identified a specific set of criteria for each one, and the database put forward a listing of different types of technologies under each category:

- *Implementation-oriented technology:* This relates to the outcomes that are practiced under clear implementation strategies.
- *Process technology:* This refers to the knowhow for implementation and practice, capacity building, and the social development for knowledge ownership.
- *Transferable indigenous knowledge:* This refers to the traditional art of disaster reduction that is indigenous to specific regions, with the potential to be applied to other regions and with time-tested reliability.

The last few years have also seen a sharp rise of new emerging technologies, like the Internet of Things (IoT), robotics, drones, 3D printing, artificial intelligence (AI), blockchain, virtual reality (VR), and augmented reality (AR) (Fig. 3). As often pointed out, the emerging technologies (PWC 2019) of today will be the essential technologies of tomorrow. Possibly within a few years, these technologies will play crucial roles in different aspects of DRR. The first documented use of a drone, for example, was in 2005 after Hurricane Katrina in the United States. Since then, drones have been used extensively in post-disaster damage estimation in different countries, and their proliferation was particularly noticeable after the 2011 East Japan earthquake, tsunami, and the nuclear accident. Artificial intelligence has been used for emergency data management, especially for managing social networks and big data. The latter is becoming common in many cases after major disasters, including the 2019 Australian bush fire monitoring. After the 2015 flooding in Chennai, different groups used Twitter as the most popular way to communicate. In Japan, robotics in disaster risk reduction have been promoted proactively, especially in search and rescue operations. 3D printing has been used extensively for specific order-made, low-cost equipment for DRR related activities. Virtual reality is used for awareness raising and educational tools to experience different types of disasters. Gradually, these technologies are becoming stronger pillars in innovation in DRR. However, the important issue is not these new/emerging technologies, but how these can be used with proper governance mechanisms, and enhancing capacities in different countries and communities. In a recent publication on disruptive technologies, ITU (2019) pointed out some crucial issues, like systematization and standardization, reach, global repository, partnership, scaling, training, legal ramifications, and adequate capacity are the factors that will define the success of disruptive technologies in the future.

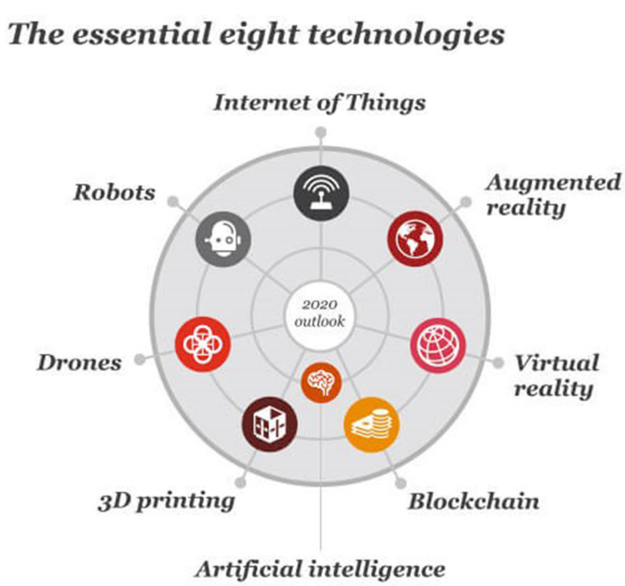

Fig. 3 Eight essential technologies. *Source* Adopted from PWC (2019)

The public is using digital technologies to support disaster management. Crowdsourcing is helping to add vital details to maps of disaster areas. Citizen science is becoming more popular and effective before, during, and after disasters. Starkey et al. (2017) described how community-based rainfall, river level, and flood observations have been successfully collected and quality-checked and used to build and run a physically based, spatially distributed catchment model, SHETRAN. Model performance using different combinations of observations is tested against traditionally derived hydrographs. This type of citizen-based data collection is becoming popular in more data-scarce countries, especially in the developing world.

Mobile applications are becoming quite popular in different fields, and the DRR field is no exception. With the goal to understand the potential benefits and drawbacks of using information and communication technology systems to communicate emergency reports and disaster risk reduction (DRR) information, the CIPG (2018) found that the Indonesian mobile phone application AtmaGo emergency alerts can reduce property damage caused by floods and other disasters by USD 324 per household per year for residents of the Jakarta region, assuming that effective action can reduce damages by about 50%. By improving community response to floods and other emergencies, AtmaGo can also reduce healthcare costs by an average of USD 14 per household per year for residents of the Jakarta region (CIPG 2018).

In spite of all these new technologies, a digital and technology divide remains, based on age, gender, economic conditions, urban or rural locations, physical disability, mentally challenged persons, and so on. The key point is how technology can overcome these digital / technological divides and create a more inclusive society when it comes to science and technology and its application to DRR.

5 Evolving Roles

Science and technology have evolved over time, and science and technology stakeholder groups have also expanded their operations over the last several years. While traditionally the science and technology stakeholder group is a closed group, mainly confined to university or research institutions and conducting academic research, there have been prominent changes globally, regionally, nationally, and more importantly locally. Although not enough, increasingly this stakeholder group is working closely with different sectors and levels of governments, private sectors, civil society, and nongovernmental organizations, as well as media. The 2004 Indian Ocean tsunami was a turning point for early warning systems and their mechanisms, and the Indian Ocean Early Warning system was installed with the participation of diverse stakeholder groups. However, for multi-hazards, cross-boundary early warning remains a challenge for many different reasons, primarily because of international relations, governance, and data sharing issues. Early warning for slow onset disasters like drought always has been a challenge. Improvements are being made, but effective early warning communication for drought remains a challenge. Increasingly, meteorological offices are collaborating with broadcasting and other media for impact-based early warning. On the occasion of 2019 typhoon Hagibis in Japan, impact-based early warning was quite effective, when not only the rainfall amount and wind speed of the typhoon were broadcast, but its impacts in terms of landslides, dyke breaks, and flooding were also shown to provide a real picture to the communities in an easy to understand way. Increasing collaboration between science and the private sectors is developing innovative products and systems related to DRR.

In addition to changes in multi-stakeholder collaboration, the science and technology communities have changed significantly over time in terms of trans-, multi-, and cross-disciplinary research. In a major development the International Science Council (ISC) (formerly known as ICSU: International Council of Scientific Unions) and the United Nations Office for Disaster Risk Reduction (UNDRR, at that time UNISDR: UN International Strategy for Disaster Reduction) established a 10-year science program—the Integrated Research on Disaster Risk (IRDR) in 2010. Its charge was to strengthen and use science and its interface with policy and practice to address the very significant and increasing challenges posed by natural and human-induced environmental hazards. The Science Plan for Integrated Research on Disaster Risk was developed as the foundation for the program of work that became known as the IRDR Program (ICSU 2008). The key mission of IRDR was to develop trans-disciplinary, multi-sectorial alliances for in-depth, practical disaster risk reduction research studies, and the implementation of effective evidence-based disaster risk policies and practices. Three specific objectives of IRDR were: (1) addressing the gaps in knowledge, methodologies, and types of information that are impeding the effective application of science to averting disasters and reducing risk; (2) emphasis on how human decisions and the pragmatic factors that constrain or facilitate such decisions contribute to hazards becoming disasters and/or may mitigate their effects; and (3) integration of outputs from the first two objectives that can only be achieved through implementing and monitoring informed risk reduction decisions, and through reductions in vulnerability or exposure (ICSU 2008). The IRDR along with its extensive network of science committees, international center of excellence (ICOE), national committees, and young scientists has contributed significantly to the development of an integrated approach in DRR. In recent years, the IRDR has started young scientist programs to facilitate integrated research of young fellows, to develop their capacities and networks, as well as to recognize the science contribution from younger communities. A similar approach—U-inspire[1]—has recently been followed by UNESCO to develop a network of young professionals and practitioners.

There are several other global initiatives on science and DRR, like the Belmont Forum (DR3: Disaster Risk Reduction and Resilience),[2] and Future Earth Risk KAN (Knowledge Action Network),[3] which promote co-design of the science-policy nexus, where the science community needs to work closely with the other stakeholders. Co-design, co-implementation, and co-delivery are becoming common in different research projects, and this increases the value of implementation-based science.

At the national level, there has been significant progress in different countries on science-based decision making by establishing a formal national science and technology advisory group. Good examples include China, Japan, Malaysia, and the Philippines, among many others. In Japan, after the 2011 earthquake and tsunami, a coalition of all professional bodies and academic society was formed under the Science Council of Japan. A joint survey was done by this coalition highlighting different disciplinary

[1] https://www.unesco.org/new/en/member-states/single-view/news/unesco_empowered_youth_and_young_professionals_in_seti_for_d/.

[2] https://www.belmontforum.org/news/belmont-forum-addresses-disaster-risk-response-and-resilience-dr3-in-its-newest-funding-call/.

[3] https://old.futureearth.org/asiacentre/call-participation-knowledge-action-network-emergent-risk-and-extreme-events-seeks-members.

approaches. This provides strong grounds for collaboration among different disciplines in a more structured way.

Grassroots or demand-driven innovation has been practiced in many countries in recent years. A regional initiative—Regional Innovation Forum (RIF)—brings together civil society, academics, private sectors, and UN agencies in Asia to discuss demand-driven innovation. In this forum, civil society brings in the key issues from the field and the science community and private sector co-design the solutions, creating demand-driven innovation. Another major development is the Coalition for Disaster Resilient Infrastructure (CDRI), which was proposed by the government of India, and supported by UNDRR and several country governments as a knowledge exchange and capacity development partnership. Four specific thematic areas include: (1) development of risk assessment methodologies, risk metrics, and indicators of sustainability for different infrastructure classes; (2) issues of standards, design, and regulation for infrastructure development, operations, and maintenance; (3) financing for disaster-resilient infrastructure, including risk transfer mechanisms; and (4) reconstruction and recovery planning for key infrastructure sectors after disasters (CDRI 2020).

6 Towards Governance in Higher Education

A significant part of science and technology development is based on higher education and research at universities and other research institutions. Multi-, trans-, and interdisciplinary courses on disaster risk reduction have been a governance challenge at many universities, where disciplinary education still prevails at the highest level. There is always a debate whether DRR should be a stand-alone course in higher education or whether it should be incorporated into different existing disciplines. Possibly the latter is easier, and there has been progress in creating DRR course modules in science (like geology), the humanities (like geography), urban planning, engineering, economics, and so on. However, in some countries, there has been strong demand for DRR professionals, and masters courses in higher education have been developed and conducted.

Higher education in DRR is a multidisciplinary issue. It encompasses all faculties of knowledge. It has not been long that some formal academic degrees have been offered in the field of DRR from a few academic institutions worldwide. Long before offering academic degrees, many institutions around the world were conducting disaster-related research and offering training programs of varying duration. The objectives of these research and training and degree programs are mainly to support local or regional needs (Shaw et al. 2011). In their analysis on higher education essentials (Shaw et al. 2011) pointed out the need for

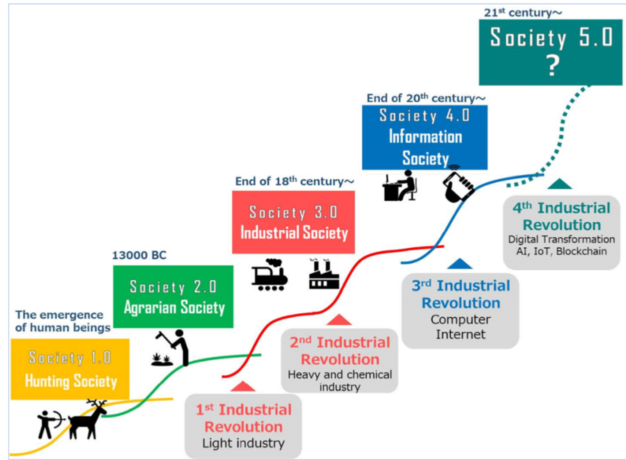

Fig. 4 Society 5.0 and its evolution. AI—Artificial Intelligence; IoT—Internet of Things. *Source* Adopted from Cabinet (Office 2017)

a balanced approach to course work and fieldwork, the importance of compulsory internship programs, research-education linkages, and the need for market mechanisms to develop and monitor the course contents, as well as the delivery mechanisms. They also stressed the importance of inclusive curriculums, theoretical focus, field orientation, a multidisciplinary approach, and skill enhancement as some of the essentials for higher education in DRR.

A recent report by Elsevier—the Global Outlook in Disaster Science (Elsevier 2017), through an analysis of all SCOPUS-indexed journal publications, showed that 0.22% of global publications were related to disaster science between 2012 and 2017, with a strong disparity between the number of disasters and human casualties and the number of articles published. More articles are published in countries with fewer human casualties, but higher economic losses. China has the largest number of publications, followed by the United States and Japan. The Relative Activity Index (RAI) of publication is calculated by dividing the share of a country's output in a particular field relative to the share of the world's output in the same field. It represents how concentrated a country's output is in a particular area relative to the world average and can be used to estimate specialization in a particular field. For instance, 0.66% of Japan's scholarly output is in disaster science, compared to 0.22% of the global scholarly output. Japan's RAI in disaster science is therefore 3, while for the United States or China it is around 1.0 or 1.2, respectively (Elsevier 2017). The study also shows that overall, the visible disasters (like earthquakes, tsunamis, typhoons, floods, volcano eruptions, and so on) receive more attention than invisible or silent disasters like droughts, heat waves, cold waves, and so on. The invisible disasters may not have high economic impacts, but cause more social problems (in education and health, for example), loss of livelihoods, and so on, and affect people more. It was also evident that the most high-risk countries have the least research funding. The report clearly distinguishes the gap areas of disaster research globally, regionally, as well as nationally.

Finally, there has also been development in new areas of business continuity plans among universities and research institutions towards having educational continuity during emergency situations. Some major disasters over the past several years have caused serious interruptions of education, and new governance mechanisms for educational continuity have been developed at many universities. The Association of Pacific Rim Universities has a multi-hazard program that developed campus safety initiatives to provide governance support in terms of facilities and infrastructures on campus, as well as educational continuity and post-traumatic stress disorder support for students in the aftermath of disasters. At several universities, university-community interaction programs (in the form of open campus activities) have been developed, which has also shown the broader role of academia and academics in society.

7 Expected Future Pathways

In a dynamic and complex world, it is difficult to propose any specific future pathways. However, here are a few elements and ideas that would possibly help in leading the future evolution of science and technology in disaster risk reduction.

7.1 Complexity of Disasters / NATECH/Systemic Risks

The nature of disasters is becoming complex, and the Sendai Framework gives additional responsibilities to better understanding different hazards, including technological and so-called NATECH (natural hazard induced technological disasters) ones. There is growing evidence, for example, from the Great East Japan Earthquake and Tsunami and the Fukushima-Daichii nuclear power plant disaster that natural hazards can trigger technological accidents that lead to natural hazard triggered technological (NATECH) disasters. These complex hazard events may have catastrophic consequences, in particular in countries that are not prepared for them. They require extended and specific risk management strategies that need to be based on a deeper understanding of their causes and cascading consequences. Although the body of knowledge concerning the management of NATECH disasters has been increasing based on reviews of the literature (Cruz and Suarez-Paba 2019), there are still large gaps in the implementation of NATECH risk management practices in countries around the world despite the fact that NATECH accidents appear to be increasing. This increase is in part due to the development of potentially dangerous industries and population growth that brings human habitat closer to industrial areas subject to high natural hazard risks. There is a clear need to address the systemic risks of complex disasters in a holistic way, and the science and technology communities have a strong role to play, from assessment and advocacy to communication.

7.2 Incubation/Social Entrepreneurship

The private sector is emerging as an important stakeholder in the field of global disaster risk reduction and sustainability policies. Engaging the private sector as part of the multi-stakeholder partnership is one of the points of confluence in the four global policies (Sendai Framework, SDGs, Paris Agreement, and New Urban Agenda). The role of the private sector has been reimagined from being a passive funding source to becoming an active stakeholder in providing innovative solutions. Science and private sector linkages in an innovation ecosystem will help in developing mindset changes in young professionals, and encourage them to be social entrepreneurs in the field of disaster risk reduction, sustainable development, and climate change, which traditionally have been development-oriented fields. A business incubator is an entrepreneur development center that helps new and start-up ideas/initiatives to develop by providing services such as management training, capital funding options, and help in providing other support in the initial phase of a setup. This kind of support is essential for the survivability of the entity in the face of hardships due to disasters and climate change, as well as to build on business opportunities related to disaster risk reduction approaches, tools, and innovations. The Resilience Innovation Knowledge Academy (RIKA), a Delhi-based DRR social entrepreneur start-up has initiated innovative incubation programs with Indian universities to develop social entrepreneurs in the DRR field.

7.3 DRR as a Professional Society

At present, there are many well-established academic organizations that focus on specific natural hazards (for example, landslides, tsunamis, storms) or certain aspects of disaster risk reduction. But no comprehensive international association exists for DRR professionals of different disciplines (for example, social, natural, and healthcare sciences), and sectors (for example, engineers, urban planners, emergency responders, and private sectors) to jointly tackle the complicated real-world challenges of DRR, and to connect professionals with different expertise for the collaborative implementation of the Sendai Framework, the SDGs, and the Paris Agreement. There is a strong need to develop an international professional society on DRR, which would help to: (1) develop DRR as an academic discipline; (2) promote cutting-edge research; and (3) develop capacities of young professionals. This would help in the career development of young professionals. Disaster risk reduction has become mature enough over the past 30 years to be recognized as an academic discipline, and a professional society would be very helpful for future work.

7.4 Society 5.0/inclusiveness

With the development of a different society, every country is aiming at smart city, smart community, and smart society development. However, the digital divide remains a major challenge. To develop an inclusive society, the Japanese government Cabinet Office created the Society 5.0 concept as a super smart and inclusive society that deals with DRR among other social needs like health care, education, agriculture, and so on. Society 1.0 was the hunting and gathering age, Society 2.0 was the agriculture age, Society 3.0 was the industry age, and Society 4.0 is the current era, the information age (Fig. 4). The future Society 5.0 is an inclusive society where different emerging technologies are connected with AI as the core and develop a resilient society. This concept has been received positively by the Japan Chamber of Commerce, and several major industries are proactive in research and development related to Society 5.0 and the SDGs. The key point is to create a balance between a techno-centric and a human-centric society that serves the purpose of all sectors of the society, making it a really inclusive society. Mavrodieva and Shaw (2020) reviewed disaster and climate change perspectives in Society 5.0 and emphasized that policy integration is key to developing an ecosystem of innovation, which leads to a sustainable and human-centric futuristic society and is disaster resilient and adaptive to climate change impacts.

7.5 The Last Mile Becomes the First Mile

We often use the phrase "the Last Mile" as the final mile to bring the research results to the communities and their usage. Possibly this is a notion when we think from the perspectives of the science and technology communities. However, from the community perspective, that should be the first mile—"the last mile" needs to become "the first mile." The essence of this is that communities and stakeholders need to be involved from the design period of the research, often called "co-design," and that needs to be linked to implementation, which also needs to be "co-delivery." Possibly that should be the future "new normal" of disaster research and the application of science and technology in DRR.

8 Conclusion

Over the last 30 years, significant changes have occurred in the evolving roles of science and technology in disaster risk reduction. Each disaster provides us an opportunity for new innovation. The last 30 years have also seen a new information and digital era, which has changed drastically the data management concept as well as information sharing. The next few years will see new emerging technologies. However, the core issue remains serving and saving the lives of the most vulnerable and needy people. Inclusive disaster risk reduction needs to break the digital divide and bring the benefits of technologies to the most vulnerable people. Traditional knowledge and wisdom, linked to modern technology, is a suitable option, where the focus needs to be on demand-driven innovation. Policy support, financial resources, capable and motivated human resources, and creating a market demand are some of the issues that the science, technology, and academia communities need to deal with in the future for a better and resilient society.

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