Building scientific capacity in disaster risk reduction for sustainable development

Fang Chen, Zeeshan Shirazi and Lei Wang
Chinese Academy of Sciences, China

Abstract
As climate warming intensifies, the frequency and intensity of disasters are also increasing, posing challenges to global sustainable development. The concept of disaster risk reduction (DRR) provides strong impetus for reducing disaster risk and vulnerabilities by employing the scientific and technological developments of recent decades. However, there is a need to enhance the capacities of different communities to use emerging digital infrastructure, not only in promoting DRR but also in ensuring sustainable future development. Limited access to and availability of data are restricting comprehensive understanding of these challenges. In many countries, the key areas for capacity development include collecting information from alternative and emerging data sources and meaningfully integrating it with data from traditional sources. Software and data analysis are becoming widely accessible due to open-source initiatives, while cloud computing technologies and programmes such as CASEarth provide valuable resources for multisource data integration, contributing to information-driven policy and decision-support systems for DRR.

Keywords
Big Earth data, disaster risk reduction, scientific capacity development

1. Introduction
The industrial revolution of the 20th century and the ongoing technological revolution have brought rapid, positive transformations in many societies and economies. The developments of this continuing process of modernization have been largely characterized by economic development and directed towards improving livelihoods to facilitate social progression (Guo et al., 2020). However, this impulsive drive towards development has produced counterproductive influences on our environment and, consequently, our own well-being, and increased our vulnerability to a large number of risks, including risks of disasters. Over time, the costs of these transitions and transformations are becoming increasingly evident, as are the complexities of mitigating these costs.

Historically, public policy in disaster research has concentrated on responding to disasters, so national disaster management plans have directed most of their funding towards response and...
recovery, ignoring the mitigation and preparedness stages of the disaster management cycle (McBean and Rodgers, 2010). Response and recovery may be aided through disaster assistance and relief in the form of international humanitarian aid and the work of volunteers from different countries and international organizations to provide respite to communities at the local level and help support rehabilitation and recovery efforts. However, these financial, material and human resources are neither unlimited nor available indefinitely. Post-disaster relief efforts are generally event-specific and not designed for long-term resilience of affected areas (Birkmann and Von Teichman, 2010). Moreover, as observed during the global COVID-19 pandemic, the capacity to provide assistance to other countries and communities is considerably constrained as the scale of a disaster increases.

From accumulated experiences of the destruction caused by unprecedented natural events, together with lessons from poor decision-making, it is now understood that, while the severity of disasters may be beyond human control, the associated risks and vulnerabilities can be managed, mitigated or reduced, giving rise to the concept of disaster risk reduction (DRR) (UN Office for Disaster Risk Reduction [UNISDR], 2015), which is focused on reducing the vulnerability and exposure of people most at risk. It has also been established that the rate of return on investment in DRR is between four and seven times (United Nations Economic and Social Commission for Asia and the Pacific [UNESCAP], 2017). Mitigating risks and exposure is increasingly becoming unavoidable, as both population increases and the changing climate are considerably complicating risk and exposure scenarios. The growth of urban populations, driven by the pursuit of better economic opportunities, has forced people to live, by choice or circumstance, in more hazardous zones. This has also increased the risk of natural hazards and raised the numbers of people and communities exposed, particularly in geographically vulnerable locations (McBean and Rodgers, 2010).

DRR is a multidimensional, multiscale, cross-cutting issue that requires input from not only the natural sciences but also the social sciences and the involvement of numerous stakeholders. In particular, with the recent drastic and sudden changes in climate (attributed to enhanced global warming), the resulting dynamic outcomes are too complex and variable to comprehend without a systematic understanding of the risks and likely consequences of ongoing developmental practices, entailing natural, socio-economic, health and engineering problems. Unfortunately, even with a consistent international focus and awareness-raising on disaster-related events worldwide, problems in implementing DRR measures persist. Rapidly developing technology and modern sciences provide new solutions to problems and new means of analysis, allowing the quantification of several aspects of disaster risk and providing opportunities to systematically study the risks and consequences of disasters. A science-to-policy approach is, therefore, needed to facilitate our understanding of the convoluted mortal and economic vulnerabilities of populations and their interests at various spatial scales. In a more connected world, policy inconsistencies resulting from administrative demarcations can be amicably reduced for shared resources, vulnerabilities and other DRR challenges through intelligible scientific evidence. Such evidence also provides opportunities to create consensus on politically sensitive issues (Carabine, 2015). However, both scientific capacity and the capacity to implement science-based solutions and policies are rather limited in many parts of the world.

2. Science, technology and innovation in the Sendai Framework and 2030 Agenda

The Sendai Framework for Disaster Risk Reduction, building on the experiences of the preceding Hyogo Framework for Action, has the single goal of strengthening resilience through two courses of action: (1) reducing risk, by lowering hazard exposure and vulnerability to disasters; and (2) increasing preparedness for response and recovery.

The goal also defines several measures, which can be divided into three domains: (1) the science domain, defined by structural, health, environmental and technological measures; (2) the governance domain, defined by economics and legal, political and institutional measures; and (3) the public
domain, comprising social, cultural and educational measures.

However, the three domains are interdependent: actions in one can overlap with actions in another, and cooperation and coordination are needed to facilitate, enable and achieve various measures. For example, the science and governance domains have strong feedback loops, while the public domain depends strongly on both of them. The Sendai Framework also identifies four key priorities: understanding disaster risk, strengthening DRR governance, investing in DRR, and responding effectively and ‘building back better’.

The DRR concept is also integral to sustainable development (Birkmann and Von Teichman, 2010); hence, DRR is embedded in the United Nations (UN) 2030 Agenda for Sustainable Development, and the Sustainable Development Goals (SDGs) have several intersections with the Sendai Framework. Examples in SDGs directly related to DRR include Target 1.5 (reduce exposure and vulnerability), Target 2.4 (improve adaptation), Target 3.d (risk reduction and management), Target 9.1 (sustainable and resilient infrastructure), Target 11.5 (reduce death, affected people and economic losses from disasters), Target 11.b (resilience to disasters), Target 13.1 (resilience to disasters), Target 13.3 (early warning systems) and Target 15.3 (prevent land-degradation and associated hazards). There are also several more targets that indirectly require improvement in DRR capacity.

Improved scientific capabilities and knowledge have enabled the role of science in several aspects of DRR. Accordingly, the Sendai Framework (unlike the Hyogo Framework for Action) clearly establishes roles for science and technology, including cultural, social, economic and natural scientists working together as a distinct (collective) stakeholder in developing a comprehensive DDR strategy (Calkins, 2015).

The UN Office for Disaster Risk Reduction (UNISDR, 2016), which became UNDRR on 1 May 2019) released ‘The science and technology road map to support the implementation of the Sendai Framework for Disaster Risk Reduction’ (see also Dickinson et al., 2016), which was subsequently revised in 2019 (UNDRR, 2019b). The road map comprehensively lists 51 actions for all four Sendai Framework priorities. These actions are intended to promote the achievement of four outcomes: improving the current state of knowledge; promptly disseminating actionable knowledge to relevant users; quantitatively monitoring progress towards DRR; and improving decision-making capacity at various levels. The road map does not recommend a particular order of actions but offers detailed guidance towards inclusive, accessible and multidisciplinary science.

The 2030 Agenda also recognizes the importance of science and technology, particularly by identifying science, technology and innovation (STI) as a key tool for implementation. The UN has also formalized the Technology Facilitation Mechanism, which was launched in September 2015 in accordance with the Addis Ababa Action Agenda. It is designed to enhance STI through multistakeholder collaboration to achieve the SDGs, with the aim of enhancing international cooperation to improve access to and sharing of technology and knowledge for sustainable development (Walsh et al., 2020).

The mechanism has three main elements: (1) a UN Inter-agency Task Team (IATT), facilitated by a 10-member group of representatives from different backgrounds, including civil society, the private sector and the scientific community; (2) a multistakeholder forum on STI for the SDGs (the STI Forum), to discuss, facilitate and support coordination and collaboration; and (3) an online platform for information on existing STI initiatives, mechanisms and programmes.

The online platform is an initiative of the UN Department of Economic and Social Affairs and the UN Office of Information and Communications Technology; it is likely to provide much-needed guidance through consolidating information on existing efforts and to help promote open and accessible exchanges of ideas and the transfer of knowledge and experiences. This online platform was launched on 15 July during the 2020 High-Level Political Forum and is currently enlisting several partners in four primary categories: publication and knowledge resources; technology solutions; financial resources and matchmaking; and capacity development and miscellaneous.
The IATT (2020) contends that the achievement of the SDGs can be facilitated and accelerated through STI and advocates urgently leveraging the potential of STI for this purpose. This is especially important because no country is currently on course to achieve the SDGs by the 2030 deadline (Walsh et al., 2020). The IATT proposes the development of STI for SDG road maps and action plans at different levels, including subnational, national and global levels, as the required information, knowledge and experience are scattered and efforts with potential to support STI are fragmented across different administrative scales (IATT, 2018). The IATT also encourages the incorporation of the various road maps into existing planning and implementation documents to avoid duplication and waste of effort and resources. In 2020, the IATT’s guidebook identified several challenges for developing countries, such as the capability to absorb, deploy and use several current technologies within existing technological infrastructures. Accordingly, the guidebook stresses the need to reassess the SDG trajectory in the light of recent progress and improved awareness about the opportunities and risks of science and technology. It also calls for leveraging digital technological transformation, emerging practices and lessons learned to formulate new and innovative solutions.

3. Scientific capacity development for DRR

With the increasing frequency and intensity of disasters, local capacities for managing hazard conditions and disaster exposure and vulnerability – founded on sound and verifiable scientific practices – are essential. Scientific capacity is, therefore, needed to innovate and develop viable solutions and also to aid the adaptation of ideas and innovations to local conditions and realities. Unfortunately, scientific capabilities, resources and expertise are unevenly distributed around the world, such that many communities struggle to incorporate scientific methods in developing DRR strategies. This is strongly reflected in Elsevier’s (2017) report titled ‘A global outlook on disaster science: from 2012 to 2016’, disaster-related research output disproportionately emanated from countries that are already prolific in scholarly output, while emerging countries—which are vulnerable to a large variety of disaster risks – generated relatively little research output. More concerning is that the countries with higher disaster mortality have low disaster research output, while countries with higher economic costs tend to have higher disaster research output.

This lack of scientific capacity is well understood in several other fields, and efforts to develop scientific capacity and technology transfer have been ongoing, entailing flows of knowledge, resources, technology and expertise from developed to developing nations (Harris, 2004). However, this process is often difficult to implement operationally, so it is critically important to understand the purpose of the capacity-development exercise (Missika, 2006). Traditional capacity-development efforts aim to improve access to education, training, funding, information, equipment and supplies; however, these resources often go underutilized due to a lack of organization, organizational structure or institutions (Missika, 2006) to enable systematic and objective work towards predefined targets and goals.

However, from a disaster-risk perspective, other capacity aspects beyond organizational and structural improvements must also be considered, such as linking climate change adaptation to DRR (Birkmann and Von Teichman, 2010; McBean and Rodgers, 2010). It is quite evident from disasters between 2000 and 2019 that both the number of disasters and their adverse consequences for lives and economies have increased considerably. In particular, the number and impacts of climate-related disasters have risen significantly, compared to those of other forms of disaster. The rate of climate-related disasters (floods, storms and droughts) accumulated to about 77% in the past two decades. Globally, although earthquakes are the deadliest disaster type, floods, droughts and storms collectively account for approximately 94% of the total number of people affected by disasters (UNDRR, 2019a). This strongly suggests that climate change and environmental degradation are linked to the rising frequency and intensity of disasters. Therefore, a well-designed DRR management plan should incorporate well-designed climate change adaptation and environmental management components to simultaneously address these multidimensional aspects.
However, DRR management plans are generally designed using historical data on risk and vulnerabilities that may change over time and under the influence of dynamic factors such as climate change, which are not regularly revised but revisited only after a disaster (Prabhakar et al., 2009). Moreover, risk assessment and modelling are often designed to detect risks that have been recognized, ignoring small but recurrent events that are equally damaging when aggregated (UNDRR, 2019a). Furthermore, since disaster vulnerability and exposure scenarios are largely unique to particular communities, DRR capabilities need to be inclusive of different forms of knowledge and enable the integration of actions at different scales (Gaillard and Mercer, 2013). This complexity in DRR requires large volumes of data, so a better balance of natural and social data in addition to local and scientific knowledge is required, and that data must be openly accessible to different stakeholders, including the affected people (Birkmann and Von Teichman, 2010). In tackling the growing challenges of disasters, integrated multidisciplinary science provides the means to develop approaches across geographical regions and addressing multiple hazards. However, scientific understanding and solutions remain neglected due to a lack of focus on generating policy-specific information that can be understood by a large variety of stakeholders and end users to enable social interventions designed to reduce risks. Therefore, there is a strong need to develop scientific capacity to translate DRR-related information to enable progress towards a science–technology–policy framework.

4. Lack of data is limiting scientific capacity

Data is quickly becoming the resource that fuels most modern digital infrastructure. However, it is largely directed towards e-commerce applications in the private sector, particularly by the services industries. While governments, particularly in developing countries, are adept in traditional data-collection methods, they have access only to limited data sources, and their data-collection mechanisms are non-periodic and inefficient. Furthermore, most African countries are unable to generate consistent, accurate and reliable data due to high costs, scattered populations and security implications, creating substantial gaps in the data needed to support policy-and decision-making (Kganyago and Mhangara, 2019); other small and developing nations face the same challenges. Consequently, the public sector in these countries is data-constrained in numerous national activities, including evaluating and monitoring DRR and the SDGs. Disaster loss data is not well maintained in many developing countries (Rautela, 2016), and the UNDRR (2019a) reports significant data gaps on disaster-related impacts and economic losses, particularly in African countries. These deficiencies are likely to be due to developmental costs and/or lack of appropriate methodologies to forecast societal development at the meso- and micro-scales, which is important for understanding changing vulnerabilities (Birkmann and Von Teichman, 2010). For scientific data, the lack of technical, financial and human resources and capabilities also contributes to the problem of non-continuous spatial and temporal data coverage.

In many developing countries, disaster science is responsive to disaster events (Elsevier, 2017), so the limited coverage and availability of data both impede comprehensive efforts to develop and apply DRR strategies. The lack of data is compounded by restricted access to available data under the policies of national administrations at various levels, aid and relief organizations, NGOs and the private sector. Reasons for access restrictions include lack of communication, low interest and simply the absence of incentives. All these factors result in the creation of data silos, which reduce the scope of information available to inform decision-making. This also causes a disconnect between bottom-up approaches to DRR, which focus on practice, and the top-down approaches, which focus on policy (Antofie et al., 2017). The lack of data (especially essential social and economic census data) further exacerbates this divide, particularly in geographical areas with dynamic fluctuations of population and economic instability.

Access to relevant data and capabilities to assess that data are crucial for identifying developmental priorities and developing baselines against which to measure a country’s current status, enabling the
identification of the correct course for developing SDG road maps and action plans (IATT, 2020). The UN and other international organizations, such as the World Bank, have undertaken several efforts to improve the data collection, data analysis and general statistical capacity of developing nations, including the Marrakesh Action Plan (Ngo, 2015) and the updated Busan Action Plan for Statistics (Organisation for Economic Co-operation and Development [OECD], 2011).

More recently, the Cape Town Action Plan for Sustainable Development Data (HLG-PCCB, 2017) identified six strategic areas for action: coordination and strategic leadership, innovation and modernization of national statistics, strengthening strategic activities and programmes, dissemination and use of data, multistakeholder partnerships, and resource mobilization and statistical-capacity development.

Data is critical to improving scientific capacity because it helps to improve in-depth understanding of disasters and associated risks, assisting decision-makers to identify and prioritize new and more adapted measures to counter disaster challenges (UNDRR, 2019a). In particular, for risks shared between communities, accessibility to data is critical for a comprehensive and collective response. Open access to data and information is, therefore, vital to addressing shared risks and challenges. Hence, it is necessary to improve the generation of evidence and to strengthen the multidisciplinary, multistakeholder, interorganizational and intergovernmental processes for DRR (Carabine, 2015).

5. Earth observation data for DRR

Whereas social data is riddled with gaps, space-based Earth observation platforms have provided invaluable synoptic and periodic data coverage over the years. Indeed, the large volumes of Earth observation data collected over the years and its integration with other spatially referenced data – enabled by improved data storage and processing capabilities – provide effective means of understanding complex multiscale and multidimensional processes and facilitate decision-making (Gulgun et al., 2009; Liang et al., 2021). Improving the spatial and temporal resolution of Earth observation data will allow the adoption of large-scale operations at local scales (Guo et al., 2018). In the past two decades, significant improvements have been made through active investments in Earth observation systems, sensors and platforms (Guo et al., 2018) to improve the viability of data using advanced algorithms and data-processing methodologies, enabling the quantification of different surface and atmospheric parameters (Guo, 2017a, 2017b).

Earth observation data has extensive applications in disaster management and multiple uses in different stages of the disaster management cycle (Le Cozannet et al., 2020), particularly in coordinating emergency responses after an event (Voigt et al., 2016) for rapid response and recovery (Lorenzo-Alonso et al., 2018).

Similarly, Earth observation data can be used to: provide logistical information for post-disaster reconstruction and rehabilitation; estimate hazard impacts and provide relevant information on risk of and exposure to disasters (Ehrlich et al., 2018); operate early-warning and monitoring systems (De Guenni et al., 2005; Van Westen, 2013); and facilitate forecasting, risk modelling and aid in recovery-related activities following disasters (Leibrand et al., 2019).

In an urbanizing world, rapidly expanding and changing urban settlements can be monitored easily using Earth observation to estimate vulnerability and risks (Chen et al., 2019). This can also help in planning for the resilience of critical infrastructure and social services by providing relevant and actionable information (Leibrand et al., 2019).

DRR science is constantly evolving with advances in Earth observation data. New and improved datasets and improvements in data-analysis techniques, the capacity to extract valuable information and the degree of geographical detail continuously advance DRR. Various aspects and disciplines of DRR science have extracted numerous benefits from developments in Earth observation technology and methods. For example, the approach to large-scale floods at each stage of the disaster management cycle has benefited greatly from Earth observation data, through improving numerical weather predictions, addressing data gaps and detecting surface water extent and heights (Alfieri et al., 2018).
Similarly, several drought indices have been developed using Earth observation data (Aitekeyeva et al., 2020), while fire-risk estimation has made extensive use of spatial and temporal Earth observation data, including by deriving information on meteorological parameters and developing new techniques to detect burned areas (Shan et al., 2017) and active fires (Lin et al., 2017, 2018, 2019). Earth observation data has also been used to develop proxies for monitoring aspects of built-up, economic, social and natural environments in urban settlements to inform disaster risk management (Ghaffarian et al., 2018).

Potential uses of Earth observation data for DRR are constantly being explored, and the development of innovative solutions has been aided by improving technology and new Earth observation systems. New satellite constellations are being developed to improve both the spatial and the temporal resolution of data, and thereby provide increasingly useful risk information. Examples include the Sentinel satellites, the COSMO-SkyMed constellation (Kwak, 2017) and the Environmental Protection and Disaster Monitoring Constellation (Guo et al., 2018). Argentina is also planning to launch SAOCOM 1B to join SAOCOM 1A and work with COSMO-SkyMed to complete the Italian-Argentine Satellite System for Emergency Management (De Ambrosio, 2020). An increasing number of governments are looking to develop in this sector. Several African nations – including Nigeria, Egypt, Algeria, Kenya, South Africa and Gabon – have established national space agencies and, in some cases, also launched Earth observation satellites (Kganyago and Mhangara, 2019).

However, there are particular developmental hurdles. Countries that have developed space-based Earth observation capabilities have had to invest extensive financial capital over several years, developing human resources and physical infrastructure in the process, but a range of limiting factors prevent many nations from pursuing the same strategy. Also, the transfer of satellite and sensor technology is a complicated state-level policy issue.

Nevertheless, data sharing is increasingly being pursued in the light of rising transboundary problems, such as global warming and the intensification of disasters, and the relevance of Earth observation data to various applications in this field makes that data ever more important. Earth observation data is especially relevant in areas lacking formal arrangements for ground-level observations, due to lack of accessibility or capacity among many other factors. Where ground-level observation data is available, Earth observation data provides complementary spatial information. Earth observation data can also help to overcome the limitations of several traditional survey methods (Kganyago and Mhangara, 2019).

Recognizing these benefits, the international community has begun to increase the volume of freely available Earth observation data, easily accessible over the internet, over the past two decades. The US Geological Survey, the National Aeronautical and Space Administration, the European Space Agency, the Japan Aerospace Exploration Agency, the National Institute for Space Research and many other organizations have large repositories of data online, while several free and open-source software packages and applications for using and analysing Earth observation datasets are already widely employed in research by the spatial data community. For immediate disaster relief, the International Working Group on Satellite-Based Emergency Mapping helps to coordinate mapping efforts for international responses to disaster events, facilitating several aspects of disaster response (IWG-SEM, 2018).

Unfortunately, Earth observation data is still underutilized for other stages of the disaster management cycle, such as vulnerability and exposure mapping (Le Cozannet et al., 2020). In developing countries, such as in Africa, the overall research output using Earth observation data is limited (Kganyago and Mhangara, 2019), which is likely to be a consequence of low internet connectivity, insufficient bandwidth for downloading the data and the poor availability of hardware able to process and analyse it. With improving digital infrastructure, such as the introduction of 5G networks and the essential processing power provided by cloud computing, the use and analysis of Earth observation data are becoming increasingly viable. Cloud computing platforms provide key capabilities for developing and disseminating products and services related to several disciplines, including DRR, and help to resolve
several of the capacity and data issues in many countries (Kganyago and Mhangara, 2019).

6. The concept of Big Earth Data: Multisource data integration

The rapid development of computers and of information and communication technology (ICT) has allowed increased interconnectivity and exchanges of data and information. Across the world, digital infrastructure is being prioritized and connectivity is improving. For instance, the numbers of fixed broadband users and internet users have risen in both Asia and Africa, especially in the past 7 or 8 years. The African Union (AU) is developing the Digital Transformation Strategy supported by the World Bank Group, AU member states and other partners to build the foundations for a digital economy, which involves establishing digital infrastructure and platforms, enhancing digital skills and introducing or improving digital financial services and entrepreneurship (IATT, 2020). More broadly, Africa, Asia and Oceania all have high growth potential and are adopting new broadband technologies (Broadband Commission for Sustainable Development [BCSD], 2018). In terms of infrastructure, the least-developed nations have lagged behind considerably, but it is expected that broadband internet user penetration will reach 35% by 2025 (BCSD, 2018), potentially accompanied by rising demand for and utility of online data analytical services.

In developed countries, interconnectivity has moved beyond the social realm into the virtual with the realisation of the internet of things (IoT), allowing the development of smart platforms. This has only been possible due to the vast amounts of data generated by human interactions with modern applications and technologies. These large datasets, commonly termed ‘big data’, have proven to be beneficial for businesses, resulting in data becoming a commodity and strategic resource in the modern world. Extensive investments and efforts are being devoted towards rapidly developing capability, capacity and infrastructure for handling big data, leading to the development of a new scientific discipline: big data science. This new discipline normally deals with four aspects of data: volume (referring to the quantity of data), velocity (referring to the speed of data generation and processing), variety (referring to the types of data) and veracity (referring to the availability and accountability of data) (Acharjya and Ahmed, 2016). Big data science and advances in artificial intelligence (AI) and machine learning are providing important opportunities for data analysis and automation (International Institute for Sustainable Development [IISD], 2018). With the rapid adoption of emerging technologies, AI and data-driven processes in all aspects of the social and economic domains, different disciplines are exploring their viability to support innovative solutions to challenges. New big-data-driven applications are fuelling platforms that employ learning-based analytics to generate valuable information and are enabling smart systems and technologies (Guo et al., 2020).

The UN has established the Global Working Group on Big Data for Official Statistics. On behalf of the working group, and in collaboration with the World Bank, the UN Statistics Division maintains an inventory cataloguing big data projects of relevance to official statistics, SDG indicators and other statistics needed for decision-making on public policies, as well as for the management and monitoring of public sector programmes and projects. The inventory summarizes innovative applications of big data in a large variety of use cases. However, a large number of projects listed are using huge volumes of data generated from ICT and the IoT; as such, their potential applications are limited to measuring social aspects and, given the availability of services, largely centred on urban areas, especially in developing regions. The inventory also includes projects applying very innovative techniques for geospatial applications, but very few focus on disaster management. There are likely to be many active projects not yet listed in the inventory. However, the projects currently listed can be regarded as representing the trend towards big-data-based research in support of global initiatives.

For a comprehensive understanding of disasters in the context of developmental and climatic changes, and to improve the current state of knowledge and monitoring of DRR progress, both domain-specific and multidisciplinary research are required.
This needs to be driven by constant streams of reliable and verifiable data, enabling the timely dissemination of actionable knowledge to relevant users through platforms and structures that provide relevant information, translate scientific knowledge into terms more adaptable for DRR policy and management, or both (Albris et al., 2020). Such platforms will help to consolidate the efforts of the Earth observation community in different domains, including the supply of disaster risk applications with better standardization of Earth observation products and services to facilitate risk assessments and enable credible and actionable information that is accessible and understandable (Lorenzo-Alonso et al., 2018).

As data sources have diversified, data integration has become an attractive and active space for innovation. The concept of integrating multisource data for earth science has been termed ‘Big Earth Data’ (Guo, 2017a); it calls for the use of both traditional methods (including statistics, mathematics, computer science, remote sensing and geographic information systems) and more advanced methods (data mining, machine learning and AI) to analyse complex and interconnected relationships. With ease of access to data and services to convert that data into information, the Big Earth Data concept has relevance in DRR and important utility in future sustainable development policies and practices. However, compared to traditional big-data analysis, Big Earth Data presents additional challenges. First, temporal and spatial scales complicate analyses of Earth observation data. Second, as multiple centres around the world develop Earth observation technology, the necessary sources and standards of data for a particular analysis are diversifying. The need to overlap different sources of data at varying scales is presenting data-interoperability challenges. Therefore, to improve the interoperability of Big Earth Data, it is necessary to establish unified standard formats, units and conversion algorithms. In the past 2 years, multiple efforts have begun to introduce, promote and facilitate the adoption of these modern emerging practices to create innovative solutions for disaster risk management and sustainable development (for details of promising examples, see Guo, 2019).

7. The CASEarth programme: Towards a Big Earth Data approach for the SDGs

In developing countries, the lack of infrastructure for processing, analysing and storing large volumes of Earth observation data, together with limited technical capability and awareness, results in the underutilization of free satellite data and analysis software (Kganyago and Mhangara, 2019). Several online services developed by different organizations are already providing access to specialized data and data-analysis facilities. Increasing accessibility due to enhanced digital infrastructure is also improving access to these resources. These developments are helping to overcome the limitations of data-processing power and data-storage capacity that complicate the use of large, integrated datasets. With the growing number and rising availability of data centres and cloud analysis services, the limitations on analysing large volumes of data and the requirement for capable hardware to process that data have been considerably reduced.

To facilitate the development of universally accessible online resources, and to provide the capability for data-intensive research on global problems, the Chinese Academy of Sciences launched the Big Earth Data Science Engineering (CASEarth) project as part of the Strategic Priority Research Programme (Guo, 2017b). CASEarth is designed to combine technical problem solving, team building and platform building. Broadly, the project is set to establish the International Research Centre of Big Data for Sustainable Development Goals, as announced by Chinese President Xi Jinping during his address to the UN’s 75th General Assembly session on 22 September 2020. CASEarth consists of several key projects designed around the themes of technological innovation, scientific discovery, macro-decision-making and knowledge dissemination.

The CASEarth project plans to launch China’s first earth science satellite in 2021, to provide Earth observation data with several potential applications in sustainability and DRR (Guo et al., 2020). The big data and cloud service platform of CASEarth is helping to overcome bottlenecks in data access and sharing (Guo, 2017b). The platform will provide access to a
diverse range of capabilities for integrating data from multiple sources and at multiple scales, which could be analysed using established algorithms and tested methodologies. CASEarth is also developing a decision-support system to facilitate transforming data into actionable information through a wide variety of scientific resources, the availability of which spares users the time and cost of developing extensive infrastructure and accessing expensive equipment.

These efforts are motivated by the need to link policy with science and to develop avenues to promote the adoption of scientific methods for policy development and decision support. For this purpose, CASEarth is working to develop case studies, model research and reference materials to encourage young talent, researchers and policymakers to use emerging technologies and data science methodologies to develop innovative solutions to challenges and national strategies for sustainable development, both within and beyond China. CASEarth has also prepared a series of reports titled *Big Earth Data in Support of the Sustainable Development Goals*, presented as part of the Chinese Government’s submissions to the UN’s 74th and 75th General Assembly sessions.

Several similar online services, which provide access to and the ability to analyse remote sensing and other forms of geospatial data from different sources, are in the early stages of development and are still expanding their user bases. They are designed to provide necessary computation power and access to large quantities of Earth observation data, along with tools to analyse and visualize that data. Making rapid progress and showing significant potential, these services provide a good direction for developing human capacity for future research and a foundation for promoting data sharing and integration. The facilities also give developing countries alternative channels to pursue science and considerably reduce their infrastructure investments, allowing them to prioritize investments in developing capacity and human resources. This will provide a strong and well-educated foundation for their future development in science and technology.

### 8. The way forward

DRR is a complex undertaking and requires an understanding of diverse multiscale processes that interlink and influence one another. A comprehensive assessment of disaster risks and challenges requires periodic information on changes in vulnerability and risk over temporal and spatial scales, in addition to information on variations in countries’ level of development, as developed nations are prone to economic risks while developing nations more typically face high mortality rates (Elsevier, 2017; UNDRR, 2019a). Therefore, the DRR community must simultaneously address a wide variety of complex socio-economic and socio-environmental challenges. The community’s efforts aim to strengthen the science–policy interface by facilitating understanding of the complicated interconnections between climate change, sustainable development and disasters, leading to meaningful and sustainable actions towards DRR.

Traditional methods and data sources are inadequate and cannot completely represent these complex relationships. Therefore, in addition to improving data collection using traditional methods, alternative and emerging data sources and methods are being developed to enhance the role of scientific and verifiable approaches in promoting viable and sustainable policies and decision-support systems. To facilitate these developments in DRR, national governments must first move from management-oriented policy to information-based policy and decision systems. This simple but critical shift will help to organize the flow of information and develop the integration of top-down and bottom-up channels, providing complementary experience and insights as the foundation for better decision-making systems. Developing countries should focus initially on national data-collection systems. They should ensure that essential development projects develop domain-specific data-collection mechanisms: for example, a project focused on agriculture or infrastructure development should establish mechanisms for collecting periodic data on various relevant indicators for the SDGs and DRR within the target area or community.

Data analysis is becoming widely accessible due to increased connectivity and open-source initiatives. AI algorithms and machine-learning techniques provide the tools to make sense of complex scenarios, along with data-analysis techniques and
methods that can be easily transferred from one place to another and communicated or disseminated through training and resource-development exercises. As in other disciplines, collaborations and human-resource-development activities can rapidly facilitate capacity enhancement within developing countries, enabling the use of these advanced techniques in DRR. However, they are data-demanding approaches, and comprehensive, integrated data analysis is especially limited by the lack of available data.

An important early step is to identify the data gaps within the knowledge- and information-management platforms that inform DRR policy. These gaps can be filled using both established and emerging data sources. Data from geospatial sources, particularly a large variety of remote-sensing platforms, is increasingly being made available, and, with the launching of multiple near-Earth orbit observation platforms, high-resolution datasets are likely to become more affordable. Over the past several years, the Earth observation community has made great efforts to improve Earth observation infrastructure, including its technology and the viability of data, for a large variety of applications, such as in DRR. Geospatial data is particularly suitable for filling the data gaps on environmental and geodynamic processes. The utility of that data will be enhanced and simplified through developments in online services, fuelled by improved cloud computing infrastructure, services and data products (Guo et al., 2020). Earth observation data and spatial data infrastructure will facilitate the linking of bottom-up and top-down approaches (Antofie et al., 2017).

However, for social processes, geographical and spatial data coverage is not always adequate, raising the need to find ways to integrate data from these different and emerging sources. Other sources of data using informal mechanisms, such as the emerging concept of citizen science, can be employed to fill the gaps. One excellent example is the formalized mechanism of participatory data collection established by the University of Namibia to aid data collection on informal settlements, the residents of which are largely vulnerable populations most exposed to disaster risks. This mechanism allows students to participate in data-collection exercises in collaboration with relevant authorities, NGOs and relief organizations. In addition to collecting valuable data, public participation in data collection raises awareness and mobilization, eventually improving public capacity for DRR.

One key challenge, however, is the integration of data from these multiple sources, including informal sources such as citizen science, telecommunications and social media. A standardization process is needed for data from these sources to be credibly incorporated in the information and data ecosystem as a complement to traditional and geospatial data. National statistical offices should develop policies to evaluate the strengths, weaknesses and limitations of these complementary sources and formalize a system to integrate them within the national data ecosystem. Proper training, data-collection protocols and standardizations can help to generate high-quality, reliable data for formal analysis and integration, even for data from non-traditional sources. Moreover, citizen science data and geospatial data can be used for cross-validating each other, which has already been demonstrated by Leibovici et al. (2017) to be useful through an automated quality-assurance workflow.

Furthermore, information from diverse sources and multiple platforms of local data, Earth observation data and big data need to be integrated in a meaningful and standardized manner to ensure credibility and acceptability. To facilitate this process of generating knowledge from integrated sources of information, there is a need for knowledge- and information-management platforms at the national and international levels, accessible to a large variety of users, to guide actions towards adopting dynamic vulnerability and adaptation strategies (Birkmann and von Teichman, 2010). The CASEarth platform for Big Earth Data provides a good example of such a system.

Regarding the lack of accessibility, public and commercial institutions are typically reluctant to make data easily and readily accessible for non-commercial scientific research. To enable the development of national capacity geared towards better DRR policies, data-sharing practices need to be encouraged and facilitated. Knowledge and information platforms will particularly facilitate this process.
and also help to prevent duplication of efforts and wasted resources in re-collecting data that has already been gathered.

Broadly, there is a need to focus on capacity-development programmes for national data collection, databases and integration systems. These activities should be facilitated through multistakeholder cooperation at both the national and international levels. The STI Forum provides one prominent example of a platform to enhance international collaboration. At the international level, efforts are needed to bridge the digital divide (Guo, 2018), as data collection and analysis are becoming increasingly digital. If the digital divide is not reduced, it might increase the global data gaps that hinder the effective monitoring of sustainable development and overall global progress. For regional-scale challenges, international collaborative agreements can help to enhance information and data sharing. This requires increased facilitation of cooperation within the Global South and between the Global North and Global South.

9. Conclusion

DRR and the drive towards sustainable development require information-driven policy and decision-support systems due to the dynamic nature of climate change and the complexity of social and environmental interlinkages. There is a need to develop scientific capacity to establish and maintain these systems through investments in data collection and analysis infrastructure. Despite the large number of data-analysis services being made available online, particularly for geospatial data, there are still data-interoperability challenges to address. Multisource data integration and analysis infrastructure, such as the workable example developed by CASEarth, cannot be replicated immediately in developing countries, as such infrastructure requires large investments and strong technical capacity. However, for such online services, improving internet connectivity will ensure accessibility for developing nations, which can thus benefit from these technological developments, although there are still data gaps to address in these regions. A large number of geospatial data sources have been developed and made available and can help to fill these data gaps. Other non-conventional data sources should also be further explored, standardized and formalized to improve our understanding of both local and regionally shared challenges. Collaboration and data sharing also need attention from multiple stakeholders at the international level. The key aims of international cooperation should be to reduce the digital divide and manage data gaps and interoperability through multistakeholder consultation, data sharing and technology transfer.

Acknowledgements

This paper is based on disaster risk reduction reports prepared by the Chinese National Committee for Integrated Research on Disaster Risk and the Digital Belt and Road Programme. We are grateful to the CAST UN Consultative Committee on Disaster Risk Reduction for its continuing support of the DRR mission.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by the Strategic Priority Research Programme of the Chinese Academy of Sciences (grant no. XDA19030101) and the National Key R&D Programme of China (grant no. 2017YFE0100800).

Note

1. See World Bank indicators at https://data.worldbank.org/indicator.

References

Acharjya DP and Ahmed K (2016) A survey on big data analytics: Challenges, open research issues and tools. International Journal of Advanced Computer Science and Applications 7(2): 511–518.

Aitekeyeva N, Li XW, Guo HD, et al. (2020) Drought risk assessment in cultivated areas of Central Asia using MODIS time-series data. Water 12(6): 1738.

Albris K, Lauta KC and Raju E (2020) Disaster knowledge gaps: Exploring the interface between science
and policy for disaster risk reduction in Europe. *International Journal of Disaster Risk Science* 11(1): 1–12.

Alfieri L, Cohen S, Galantowicz J, et al. (2018) A global network for operational flood risk reduction. *Environmental Science and Policy* 84: 149–158.

Antofie T-E, Casajus VA, Doherty B, et al. (2017) Identifying Challenges in Disaster Risk Reduction: Risk Data Hub for Disaster Risk Management. Luxembourg: Publications Office of the European Union.

BCSD (Broadband Commission for Sustainable Development) (2018) *The State of Broadband: Broadband Catalyzing Sustainable Development*. Geneva: International Telecommunication Union.

Birkmann J and Von Teichman K (2010) Integrating disaster risk reduction and climate change adaptation: Key challenges—scales, knowledge, and norms. *Sustainability Science* 5(2): 171–184.

Calkins J. Moving forward after Sendai: How countries want to use science, evidence and technology for disaster risk reduction. Available at: https://currents.plos.org/disasters/index.html?%3Fp=20358.html (accessed 13 May 2021).

Carabine E (2015) Revitalising evidence-based policy for the Sendai Framework for Disaster Risk Reduction 2015–2030: Lessons from existing international science partnerships. *PLoS Currents Disasters* 7: 1–21.

Chen F, Guo HD and Shirazi Z (2019) Disaster risks and response strategies in process of urbanization in China. Available at: https://www.unisdr.org/files/65948_f318chendisasterrisksandresponsestr.pdf (accessed 16 April 2021).

De Ambrosio M (2020) Volcanoes and floods: How satellites monitor disasters. Available at: https://www.scidev.net/global/disasters/feature/volcanoes-and-floods-how-satellites-monitor-disasters.html (accessed 28 October 2020).

De Guenni BL, Cardoso M, Goldammer J, et al. (2005) Regulation of natural hazards: Floods and fires. In: Hassan R, Scholes R and Ash N (eds) *Ecosystems and Human Well-being: Current State and Trends*, vol. 1. Washington, DC: Island Press, pp.443–453.

Dickinson C, Aitsi-Selmi A, Basabe P, et al. (2016) Global community of disaster risk reduction scientists and decision makers endorse a science and technology partnership to support the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030. *International Journal of Disaster Risk Science* 7(1): 108–109.

Ehrlich D, Melchiorri M, Florczyk A, et al. (2018) Remote sensing derived built-up area and population density to quantify global exposure to five natural hazards over time. *Remote Sensing* 10(9): 1–20.

Elsevier (2017) A global outlook on disaster science. Available at: https://www.elsevier.com/__data/assets/pdf_file/0008/538091/ElsevierDisasterScienceReport-PDF.pdf (accessed 16 April 2021).

Gaillard JC and Mercer J (2013) From knowledge to action: Bridging gaps in disaster risk reduction. *Progress in Human Geography* 37(1): 93–114.

Ghaffarian S, Kerle N and Filatova T (2018) Remote sensing-based proxies for urban disaster risk management and resilience: A review. *Remote Sensing* 10(11): 1760.

Gulgun B, Yörük İ, Turkyilmaz B, et al. (2009) Determination of the effects of temporal change in urban and agricultural land uses as seen in the example of the town of Akhisar, using remote sensing techniques. *Environmental Monitoring and Assessment* 150(1–4): 427–436.

Guo HD (2017a) Big data drives the development of earth science. *Big Earth Data* 1(1–2): 1–3.

Guo HD (2017b) Big Earth data: A new frontier in earth and information sciences. *Big Earth Data* 1(1–2): 4–20.

Guo HD (2018) Steps to the digital silk road. *Nature* 554: 25–27.

Guo HD (2019) *Big Earth Data in Support of Sustainable Development Goals*. Beijing: Science Press and EDP Sciences.

Guo HD, Liu G, Liang D, et al. (2018) Progress of earth observation and earth science in China. *China Journal of Space Science* 38(5): 797–809.

Guo HD, Nativi S, Liang D, et al. (2020) Big Earth data science: An information framework for a sustainable planet. *International Journal of Digital Earth* 13(7): 743–767.

Harris E (2004) Building scientific capacity in developing countries. *EMBO Reports* 5(1): 7–11.

HLG-PCCB (High-Level Group for Partnership, Coordination and Capacity-Building for Statistics for the 2030 Agenda for Sustainable Development) (2017) Cape Town global action plan for sustainable development data. Available at: https://unstats.un.org/sdgs/hlg/Cape_Town_Global_Action_Plan_for_Sustainable_Development_Data.pdf (accessed 16 April 2021).

IATT (United Nations Interagency Task Team on Science, Technology and Innovation) (2018) Science, technology and innovation for SDGs roadmaps. Available
at: https://sustainabledevelopment.un.org/content/documents/19009STI_Roadmap_Background_Paper_pre_STI_Forum_Final_Draft.pdf (accessed 16 April 2021).

IATT (2020) Guidebook for the preparation of science, technology and innovation (STI) for SDGs roadmaps. Available at: https://sustainabledevelopment.un.org/content/documents/26937Guidebook_STI_for_SDG_Roadmaps_final_Edition.pdf (accessed 16 April 2021).

IISD (International Institute for Sustainable Development) (2018) Summary of the second UN world data forum: 22–24 October 2018. UN World Data Forum Bulletin 232(2): 22–24.

IWG-SEM (International Working Group on Satellite-Based Emergency Mapping) (2018) IWG-SEM white paper: The proposition: EWS potential in reducing the time lag between a catastrophic event and satellite data acquisition. Available at: https://www.un-spiderc.org/sites/default/files/IWG-SEM_Rapid%20Mapping%20and%20Early%20Warning%20Systems%20v1.0.pdf (accessed 13 May 2021).

Kganyago M and Mhangara P (2019) The role of African emerging space agencies in Earth observation capacity building for facilitating the implementation and monitoring of the African development agenda: The case of African Earth observation program. ISPRS International Journal of Geo-Information 8(7): 292.

Kwak Y-J (2017) Nationwide flood monitoring for disaster risk reduction using multiple satellite data. ISPRS International Journal of Geo-Information 6(7): 203.

Le Cozannet G, Kervyn M, Russo S, et al. (2020) Space-based Earth observations for disaster risk management. Surveys in Geophysics 41(6): 1209–1235.

Leibovici DG, Williams J, Rosser JF, et al. (2017) Earth observation for citizen science validation, or citizen science for Earth observation validation? The role of quality assurance of volunteered observations. Data 2(4): 1–20.

Leibrand A, Sadoff N, Maslak T, et al. (2019) Using Earth observations to help developing countries improve access to reliable, sustainable, and modern energy. Frontiers in Environmental Science 7: 1–14.

Liang D, Guo HD, Zhang L, et al. (2021) Analyzing Antarctic ice sheet snowmelt with dynamic Big Earth Data. International Journal of Digital Earth 14(1): 88–105.

Lin ZY, Chen F, Li B, et al. (2017) FengYun-3C VIRR active fire monitoring: Algorithm description and initial assessment using MODIS and Landsat data. IEEE Transactions on Geoscience and Remote Sensing 55(11): 6420–6430.

Lin ZY, Chen F, Li B, et al. (2019) A contextual and multi-temporal active-fire detection algorithm based on FengYun-2G S-VISSR data. IEEE Transactions on Geoscience and Remote Sensing 57(11): 8840–8852.

Lin ZY, Chen F, Niu Z, et al. (2018) An active fire detection algorithm based on multi-temporal FengYun-3C VIRR data. Remote Sensing of Environment 211: 376–387.

Lorenzo-Alonso A, Utanda A, Aullo-Maestro M, et al. (2018) Earth observation actionable information supporting disaster risk reduction efforts in a sustainable development framework. Remote Sensing 11(1): 49.

McBean G and Rodgers C (2010) Climate hazards and disasters: The need for capacity building. Wiley Interdisciplinary Reviews: Climate Change 1(6): 871–884.

Missika B (2006) The challenge of capacity development: Working towards good practice. Available at: http://gsdrc.org/docs/open/cc110.pdf (accessed 13 May 2021).

Ngo BT (2015) Independent evaluation of the Marrakech action plan for statistics. Available at: http://documents1.worldbank.org/curated/en/655691468000594954/pdf/96525-WP-PUBLIC-Box391449B-MAPS-evaluation-report-2015-final-PUBLIC.pdf (accessed 13 May 2021).

OECD (Organisation for Economic Co-operation and Development) (2011) Statistics for transparency, accountability, and results: A Busan action plan for statistics. Available at: https://paris21.org/sites/default/files/Busanactionplan_nov2011.pdf (accessed 13 May 2021).

Prabhakar SVRK, Srinivasan A and Shaw R (2009) Climate change and local level disaster risk reduction planning: Need, opportunities and challenges. Mitigation and Adaptation Strategies for Global Change 14(1): 7–33.

Rautela P (2016) Lack of scientific recordkeeping of disaster incidences: A big hurdle in disaster risk reduction in India. International Journal of Disaster Risk Reduction 15: 73–79.

Shan TC, Wang CL, Chen F, et al. (2017) A burned area mapping algorithm for Chinese FengYun-3 MERSI satellite data. Remote Sensing 9(7): 736.

UNDRR (UN Office for Disaster Risk Reduction) (2019a) Human cost of disasters: An overview of the last 20 years. Available at: https://www.undrr.org/sites/default/files/inline-files/Human%20Cost%20
of%20Disasters%202000-2019%20FINAL.pdf (accessed 13 May 2021).

UNDRR (2019b) The science and technology roadmap to support the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (revised edition). Available at: https://www.preventionweb.net/files/65131_file.pdf (accessed 13 May 2021).

UNESCAP (United Nations Economic and Social Commission for Asia and the Pacific) (2017) Leave no one behind: Disaster resilience for sustainable development. Available at: https://www.unescap.org/sites/default/files/knowledge-products/0_Disaster%20Report%202017%20High%20res.pdf (accessed 13 May 2021).

UNISDR (UN Office for Disaster Risk Reduction) (2015) Making Development Sustainable: The Future of Disaster Risk Management. Geneva: UNISDR.

UNISDR (2016) The science and technology roadmap to support the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030. Available at: https://www.unisdr.org/files/45270_unisdrscienceandtechnologyroadmap.pdf (accessed 13 May 2021).

Van Westen CJ (2013) Remote sensing and GIS for natural hazards assessment and disaster risk management. In: Shroder J and Bishop MP (eds) Treatise on Geomorphology. San Diego, CA: Academic Press, pp.259–298.

Voigt S, Giulio-Tonolo F, Lyons J, et al. (2016) Global trends in satellite-based emergency mapping. Science 353(6296): 247–252.

Walsh PP, Murphy E and Horan D (2020) The role of science, technology and innovation in the UN 2030 Agenda. Technological Forecasting and Social Change 154: 119957.

Author biographies

Fang Chen, PhD, is a professor at the Aerospace Information Research Institute, Chinese Academy of Sciences (CAS). Dr Chen conducts interdisciplinary work combining remote sensing, ecology and other fields of study to assess spatial patterns of disaster risk. He is currently serving as Deputy Director of the Key Laboratory of Digital Earth Science of CAS, Secretary-General of the Chinese National Committee for Integrated Research on Disaster Risk, Deputy Secretary-General of the Digital Belt and Road Programme, Executive Deputy Director of the CAS–TWAS Centre of Excellence on Space Technology for Disaster Mitigation and member of the World Federation of Engineering Organizations Committee on Disaster Risk Management.

Lei Wang, PhD, is an associate professor at the Aerospace Information Research Institute of CAS. Dr Wang investigates methods, causes and impacts of global land cover change, focusing especially on urbanization and forest disturbance.

Zeeshan Shirazi, PhD, is a scientific officer at the Key Laboratory of Digital Earth Science of CAS. He is working to develop use cases for applying multisource data in DRR.