Progress in Disaster Science 16 (2022) 100254

Contents lists available at ScienceDirect

Progress in Disaster Science

journal homepage: www.elsevier.com/locate/pdisas

Harnessing risk-informed data for disaster and climate resilience

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ARTICLE INFO

Keywords:
Disaster risk reduction
Climate change
Data-driven
Risk management
FAIR data

ABSTRACT

Disaster and climate risks result from a complex interaction between hazard, exposure, and vulnerability in a broad context defined by socioeconomic, political, and ecological factors. To better understand the risk and manage it more effectively, we need to collect, store, analyse, and use risk-informed data. We identified challenges and opportunities for harnessing risk-informed data for disaster and climate resilience. The framework is inspired by the FAIR (findable, accessible, interoperable and reusable) and CARE (collective, authority to control, responsibility and ethics) principles to discuss opportunities how data could be available to inform risk-informed decision-making in climate and disaster risk management. Looking ahead, data could be developed and integrated with societal needs and participation. The use of data for risk management necessitates a common definition of risk to ensure a comparable research and development process. The world is shifting from a "for-profit" to a "for-benefit" operating model, which needs a Fifth Industrial Revolution driven by and for data for the benefit of society.

1. Introduction: The role of data in improving our understanding of disaster and climate hazards

Disaster and climate risks result from complex interactions of hazard, exposure, and vulnerability [56]. These elements are defined in different ways in the literature. To increase understanding of the risks, relationships between these risk elements need to be modelled and understood in a broader socioeconomic, political, and ecological context [21,27,33]. This requires relevant data from the national to the community level. In addition, data standardisation and interoperability need to be ensured [37,41,63]. For instance, standardisation of loss data quantification can assist in identifying gaps in vulnerability or risk assessment [19]. Risk-informed data is the analytical data product based on a structured approach to managing risks by identifying, assessing, and monitoring hazards, exposure and vulnerability [29]. Risk-informed data assist in decision making by using risk acceptability, prioritization, and stakeholder engagement [32].

Accessing underutilised or unexplored data or data sources could be a valuable resource for assessing vulnerabilities ([2,46]). A systematic approach to drivers of vulnerability and their impacts is essential. Data shall be open as possible and as closed as necessary, while embracing FAIR (findable, accessible, interoperable and reuseable) and CARE (collective, authority to control, responsibility and ethics) principles [10]. The FAIR guiding principles described by Wilkinson et al. [83] provide a succinct and measurable set of concepts to be used as a guideline for improving the access and reusability of data for human users and machines.

1.1. Importance of vulnerability and risk data

Vulnerability and risk terms have different definitions explaining their meaning and are used differently in many assessments ([17,25]). Vulnerability is 'the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards' [56]. Vulnerability is assessed through sensitivity and adaptive capacity [25,26]. Comprehensive vulnerability assessment requires additional elements such as understanding the influence of institutional and social networks [35], the influence of data integration, sharing,

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https://doi.org/10.1016/j.pdisas.2022.100254
Received 17 May 2022; Received in revised form 21 September 2022; Accepted 24 September 2022
Available online 27 September 2022

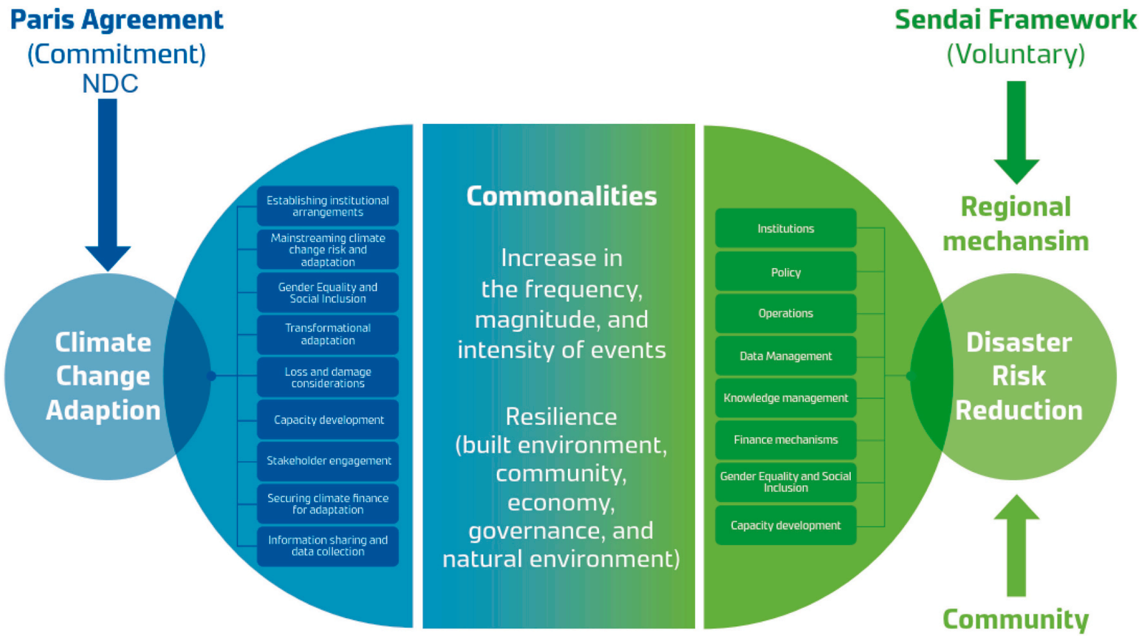


Fig. 1. Relationship between climate change adaptation and disaster risk reduction.

interoperability, and quality to enhance the baseline information and to understand the vulnerability of risk elements [6]. Therefore, a systematic collection of disaggregated data is necessary to understand the drivers of vulnerability [6,38,39,45].

1.2. Opportunity of data-driven risk management strategy

Data-driven risk management collects and analyses data from multiple sources using advanced data collection and analytical tools and technologies to identify, forecast, and mitigates the risks leading to an effective risk management [28]. It depends on whether and how to (re)use datasets, which rely on data availability and quality, including data completeness, accuracy, provenance, and timeliness [13,43]. This raises the question of "how to mainstream a data-driven comprehensive risk management strategy". The progress is measured by analysing the exposure, vulnerability, socially determined capacities and capacity needs of vulnerable elements in preparedness, response, and recovery. This analysis requires various socioeconomic and physical parameters (including gender, age, ability, ethnicity, income, geographic location, and asset conditions). Currently, data available with various organisations often unused or underutilised ([2,46]). For instance, the data for Sustainable Development Goals monitoring are not frequent applied to accelerate disaster risk reduction. Also, the data-driven risk management approach may include bias, errors, assumptions, and interpretations.

The availability at the normative and operational levels in addressing these issues should be contemplated. Additionally, with the progress and increased use of Artificial Intelligence (AI) and other data-driven tools, the role of data becomes pivotal in understanding data integrity and representativeness and the gaps.

2. Challenges of collecting and using risk-informed data for disaster and climate resilience

Assessment of hazard, vulnerability and risk of disaster and climate change is essential in order to inform and implement appropriate adaptation/prevention/mitigation strategies. Establishing a comprehensive standardised database and management system is complex due to its multi-sectoral, multi-layered requirements across the public and private sectors. The value of such systems is now well-proven and of benefit when comparing impacts and loss on a global scale. However, several challenges remain at both local and international levels, including limited resources, financial constraints and decision-making. These challenges have numerous complex factors, which lead to inappropriate risk assessment and understanding of cascading and compounding consequences in the communities affected by the disaster.

2.1. Complex data management mechanisms

The Sendai Framework for Disaster Risk Reduction, the United Nations Sustainable Development Goals, and other global frameworks on disaster risk reduction and climate change include at least one indicator that can improve data management [55,60]. Achieving data management targets is difficult due to complex data collection, storing, and sharing mechanisms [7,40,42].

2.2. Limited capacity to manage data

Data across various components (e.g., geographic disparities, infrastructure, economic, human, social, technological) is necessary to understand sustainability or the capabilities of a community to withstand a future disaster or a slow-onset event. Limited data management mechanisms, low technical and human capacity to manage data, and inadequate access to secondary data create challenges to understanding such concepts [42].

2.3. Underutilised and unexplored data

Historical data recorded in paper form is not utilised sometimes to understand the trends and frequency of hazards. Similarly, there are disaggregated data at the national or regional level. However, these data may not be available at a centralised location or in a readily useable form, and hence they may remain underutilised and possibly unexplored [2,11,46,61]. This is a missed opportunity for targeted social policy as part of risk reduction.

2.4. Lack of useable, clear, and complete data

Using agreed and collected data in a useable format to create information and knowledge products has many benefits. Currently if collected data cannot produce rapidly available and usable information for the user, it is considered unusable [40]. Also of concern, incomplete

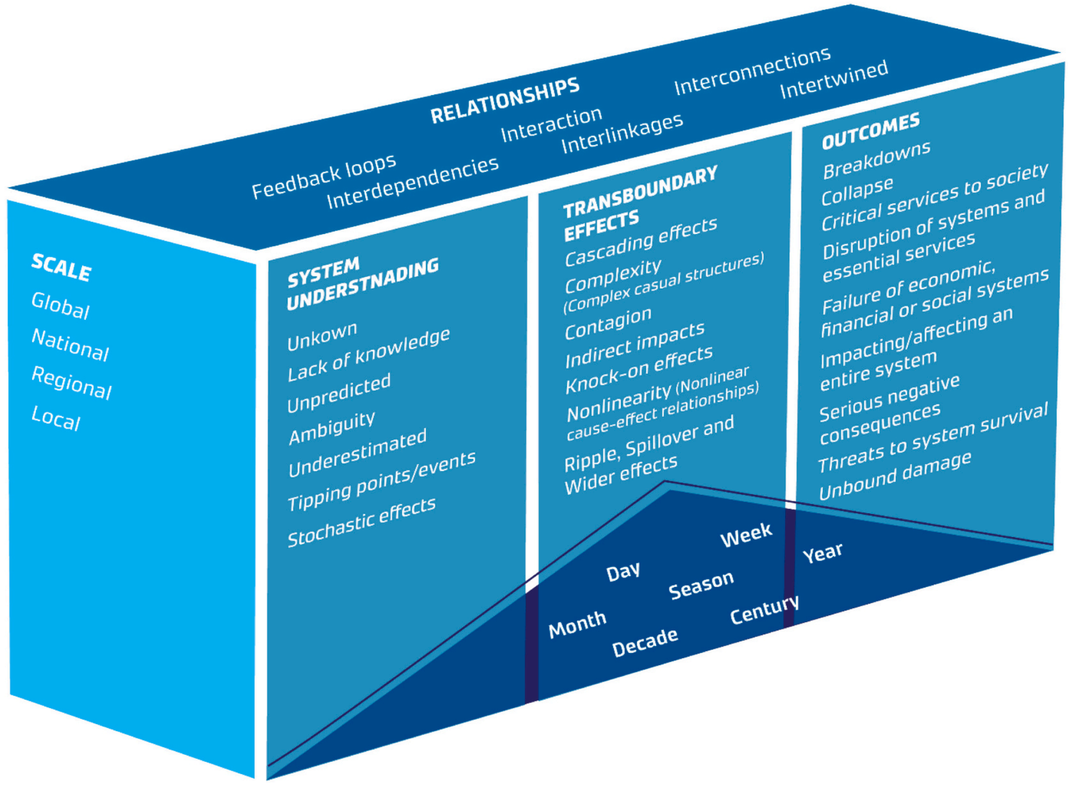


Fig. 2. Attributes of systematic, interconnected, and cascading risk (modified from [49]).

datasets can create ambiguity in making decisions and may cause misinterpretation and manipulation of information [47].

2.5. Lack of integration between climate change adaptation and disaster risk reduction

Climate change adaptation is the process of adjustment to actual or expected climate variation and its effects by either avoiding or controlling the impacts, with disaster risk reduction being the process at preventing new and reducing existing disaster risk and managing residual risk [57]. Climate change adaptation and disaster risk reduction contribute to strengthening resilience, but the processes and activities supporting the climate change adaptation and disaster risk reduction related frameworks are distinct and not always well-coordinated [57]. Responses to climate change impacts and disaster risks are often siloed and can be managed through different agencies (Fig. 1), leading to duplication of activities, investments, and efforts [58]. According to [84], coherence between climate change adaptation and disaster risk reduction is a defining issue for disaster risk governance in the 21st century. The relationship between climate change adaptation and disaster risk reduction is shown in Fig. 2.

2.6. Lack of data sharing mechanisms

Although large amounts of disaster-related scientific data exist today, they are typically dispersed geographically and owned by various entities, including government agencies, research centres, community groups and, sometimes, individuals making them difficult to access and utilise for response, research and even for informing decision making. Institutional silos i.e., organisations that operate independently due to inadequate communication, lack of technology platforms, can prevent interoperability between the organisations, and complicated data sharing.

2.7. Lack of data standardisation

Data standardisation is the process of bringing data into a common format that allows for collaborative research, large-scale analytics, and sharing of sophisticated tools and methodologies [77]. However, data is not standardised, and the demand for standard methodology for quantification of data quality remains unmet, as data is collected from various sources for different uses and may be stored in various formats. Such data management may lead to duplication of information and efforts, inconsistencies in decision making and reporting, and low-quality and unreliable information (Judge & Berner, 2019).

Also, the increase in frequency, intensity, severity, and impacts of disasters across the world demands enhanced risk information across all types of hazards. Such information can improve the capacity to predict, avoid, and respond to threats and impacts posed by disasters from the local to the global scale [31]. Recognising this issue, UNDRR and the International Science Council have published the UNDRR/ISC Hazard definition and classification review in 2021 and the Supplement to the UNDRR-ISC Hazard Definition and Classification Review - Technical report in 2021. The UNDRR/ISC Sendai Hazard Definition and Classification Review Technical Report and the UNDRR/ISC Hazard Information Profiles supports all three by providing a common set of hazard definitions for monitoring and reviewing implementation which calls for "a data revolution, rigorous accountability mechanisms and renewed global partnerships" [34].

The lack of UNDRR/ISC standardised definitions of severity of hazards, vulnerability (conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards) and impact remain important issues that need to be addressed.

2.8. Lack of data on human decisions at local scale

Decision-making during an emergency is heavily influenced by the responders past experiences, a variety of biases, opinions of team members, socioeconomic status, and practitioners' beliefs [14,15,75]. Currently, data is available in various sources, but there is a lack of provision to incorporate management decisions and human emotions and perceptions into the models to understand their influence on the geophysical system.

2.9. Lack of data availability

The practitioners and responders during disaster events need accurate, reliable, and timely data to ensure the response activities are effectively and efficiently managed [14,15]. Data is needed for preparedness and recovery activities to make sure appropriate mechanisms are in place for creating resilient communities. However, data is sometimes not freely and openly available for the decision makers [1,53].

2.10. Lack of data for assessing systemic risks

Systemic risk is linked with the unforeseen chain of events, i.e., cascading impacts that span within and across systems and sectors such as infrastructure, agriculture, and health, through the movements of physical, social, and economic capital, and information within and across regions, countries, and continents [49]. The Sendai Framework for Disaster Risk Reduction 2015–2030 calls for a fresh understanding of the systemic risk, relationships that exists across regions, countries, and continents, new governing structures to manage risk in complex, adaptive systems, and supporting tools for risk-informed decision making [57]. Data required for identifying the systemic risks and transboundary relationships may not be known or cannot be measured or modelled with the current understanding of the risk and the available tools. Increased complexity and uncertainties were experienced while modelling the system boundaries that could capture interactions and characterise the systemic risk ([49]; [78]).

3. Recommendations

To overcome the challenges of collecting and utilising risk-informed data for disaster and climate resilience drastic actions need to be taken collectively. Various initiatives are ongoing such as the 'Committee on Data of the International Science Council (ISC)' by promoting Open Science and FAIR data. CODATA convenes a global expert community and provides a forum for international consensus building and agreements around a range of data science and data policy issues, from the fundamental physical constants to cross-domain data specifications.

3.1. Promoting comprehensive disaster and climate risk management

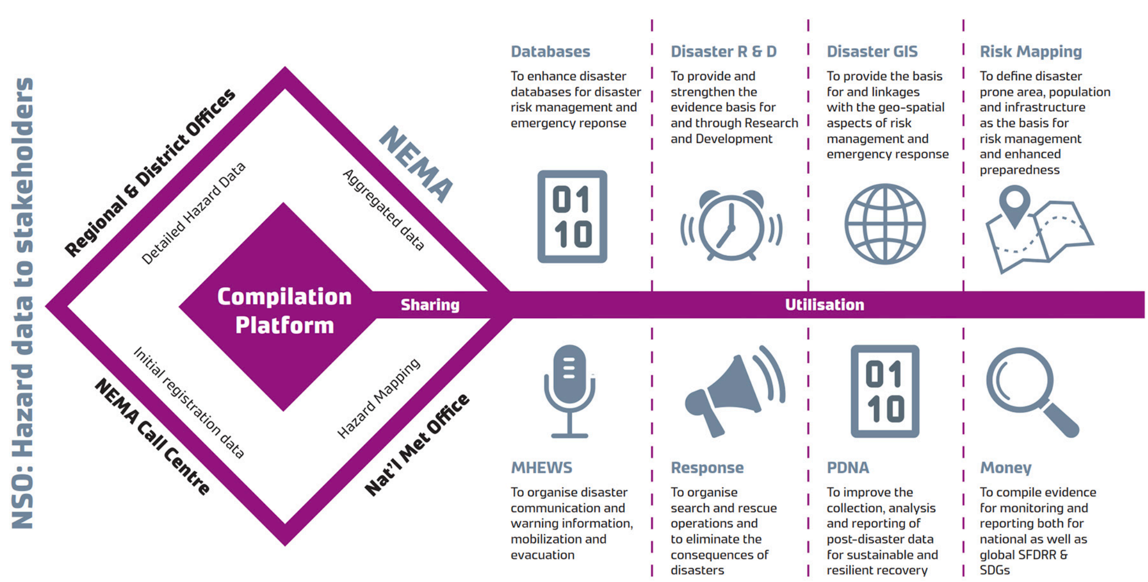
To promote comprehensive disaster and climate risk management, the integration of climate change considerations into disaster risk reduction policies and actions could be considered. To further support a wide-ranging disaster and climate risk management, technical support, and policy advice on risk-informed adaptation (including United Nations Framework Convention on Climate Change (UNFCCC) processes) could be provided. This could be supported by establishing partnerships and alliances. By integration, several duplication efforts could be avoided (e.g., loss and damage consideration for climate change linking with national disaster loss database) (Fig. 1).

3.2. Improving coordination and engagement

Improving coordination between data managing agencies and practitioners could improve the quality of the data. Linking climate scientists, urban planners, engineers, and sectoral professionals would contribute to identify future disaster and climate change risks. Moreover, engaging with users and sectors to achieve a greater alignment and consistency of hazard definitions is needed. Creating new public private collaboration enables utilisation of advanced technology and supports creating better models or tools. The case example highlights the benefits of data sharing and coordination that are practised in Mongolia.

Case example: Historical and projected impacts of climate change –Mongolia

In Mongolia, disaster risk information is compiled and shared between the National Emergency Management Agency, the National Statistics Office and National Meteorological Office. The accumulated data is shared widely, and databases, geoinformation systems and risks mapping can be performed. This leads to a strengthening of research and development in this area. In a practical sense, data is used to organise disaster communication and warning information which leads to timely mobilisation and evacuation of the affected population. It serves to organise search and rescue operations. After a disaster occurs, the additional data increases the wider data collection which improves the analysis and reporting of post-disaster data for sustainable and resilient recovery. Data supports the compilation of evidence for monitoring and reporting for both national and global goals. The image below presents the framework for collection, sharing and utilisation of data by Mongolia's NEMA and other agencies.



3.3. Scaling up local actions to build resilience

There are several frameworks, plans and works of literature with various benchmarks and indicators across the globe to support nations, community and organisations in planning and implementing measures for climate change and disaster risks and to enhance the resilience of coastal communities ([62]; R[3,44]). However, most of them do not cover all aspects comprehensively as governments tend to value various aspects of community resilience differently. For example, Making Cities Resilient (MCR) 2030 aims to tailor systemic risk analytics for urban settings or sectors. The application would strengthen climate change and disaster risk reduction metrics and scale up the local actions to build resilience [[74]). An integrated approach for community resilience is needed to support and to assist various organisations involved in preparedness, response, and recovery in incorporating disaster risk reduction and climate change measures to improve resilience in communities.

3.4. Managing systemic risk

Adaptive and integrative approaches along with appropriate evidence are essential to conduct the systemic risk assessment. As systemic risks emphasis on the transboundary effects and impacts on systems at different scales, it is important is necessary to be specific about the system, effects on boundaries and trans-boundaries, methodologies, and assumptions. Shifting the focus from individual hazard and risk assessment to a transdisciplinary system analysis with relevant research on disaster risk involving multiple stakeholders is needed ([49]).

A relational and trans-contextual perception can support in understanding the personal and political domains within a system and can increase trust and buy-in by decision makers as it includes all contexts (such as societal values, belief systems, locations, emotional, cultural, and/or spiritual values that motivates decision making) and is possible to develop in an open and all-encompassing process ([79]; [49]). A toolbox approach may support understanding the multidimensional challenges associated with the systemic risk and the variety of approaches and methodologies needed [4].

Interdisciplinary and cross-sectoral collaboration and engagement from scientists, policy makers, government authorities, private organisations, and other stakeholders is needed to govern the systemic risks. Knowledge sharing and communication with stakeholders plays a vital role in developing information products, analysis, and risk governance [80,81]. Besides, to meet the societal needs and global agendas, systems understanding, or system thinking can assist organisations in engaging and interacting stakeholders to advance science. Thus addressing systemic requires systemic solutions.

3.5. Improving information ecosystems

There is no single model or tool system that assists in solving data related problems; therefore, testing the models or tools under various scenarios (e.g., different demographics, climate projections) and contextualising it to the local perspective improve the information ecosystems. Information ecosystems also need to be about collecting data in new, innovative ways and improving feedback and learning loops.

3.6. FAIR vocabulary of hazards and vulnerability

Shared terminology is key to accurate communication and an enabler for data integration [12]. Standard knowledge representation languages for disaster and climate risk assessment are essential for common understanding. A revised hazard definition and classification developed by International Science Council and the United Nations Office for Disaster Risk Reduction [34] to actively engage policymakers and scientists in evidence-based national risk assessment processes, disaster risk reduction and risk-informed sustainable development, and other actions aimed at managing risks of emergencies and disasters. A FAIR vocabulary for vulnerability and risk could enhance the sectoral risk assessment and consistency in adaptation options development. It is recommended to regularly review and update the definition of hazards, exposure and vulnerability and engage with users and sectors for greater alignment and consistency of hazard definitions. CODATA and Research Data Alliance (RDA) are leading and coordinating some activities such decadal programme: making data work for cross domain grand challenges, World-FAIR to to advance implementation of the FAIR principles and, in particular, to improve interoperability and reusability of digital research objects, including data, within and across a number of research disciplines.

3.7. Change of narrative

The current understanding of climate vulnerability and future hazards is driven by global models, i.e., the current solution strategy is developed through the global model lens and is greenhouse gas reduction centric. Focusing the narrative and approach to local, bottom-up and horizontal approach for vulnerability assessment rather than using global downscaling could improve data quality [82] The current metrics and way of measuring value requires updating to consider other intra and inter connectedness among vulnerable elements.

3.8. Utilising big data

Big data have the potential to improve disaster management through data visualisation and predictive analytics [85]. The case example presented below in the box highlights the infrastructure needed for big data and the strategies that can be utilised to improve the usage of data in disaster risk management.

Case example: Big data infrastructure- Indonesia

Indonesia set a goal to create and manage value generated from big data (big data value). The principles to achieve this are: data protection and privacy, security, stewardship, optimisation, excellence, and asset. This will be supported by fairness, accountability, transparency, ownership, agency, and inventory. One of the strategies to accomplish this challenge is 'Personal Information Protection'. The level of data protection should be defined, and systematic protection tools need to be developed. Another strategy is 'Data Quality Level' ensuring that the provided data is timely, trustful, meaningful, and sufficient. The third strategy is 'Responsibility/ Data Disclosure': It is required to define the responsibility for data ownership and management as well as the scope of data disclosure. A reliable IT infrastructure (Big Data Infrastructure) is at the base to support the components such as an organised and well-managed audit and control, risk management supported by standards and guidelines and supporting policies and processes to deal with occurring challenges and opportunities.

3.9. Climate hazard YIMBY (Yes in my backyard)

Focusing on the principle of 'make climate local', producing higher spatial resolution for Earth system models, and including more local processes and parameters need to become the driver of products, tools and processes. For example, in a 100 × 100 km grid climate model, a city would be a "sub-grid" approximation; in finer grid models, cities need to be represented; with agriculture; and human decisions and management practices should be identified. These 'local scale climate information' will need to translate the climate information as equivalent of YIMBY.

3.10. Promoting open data

Data is a critical asset for developing meaningful insights and evidence to make informed decisions, information products and policy building [51] especially in the disaster and climate change management space. Data shall be readily and openly available to generate accurate, relevant, and useable information products such as hazard maps and models. The following case example explores the benefits of open loss data interconnectivity for earthquake disaster risk management.

Case examples: Earthquake disaster risk management and CODATA

Earthquake disaster risk reduction is an international task. The cooperation of earthquake prone countries and international organisations is extremely important to tackle the risks posed by the earthquake. Reliable near real time earthquake loss estimation allows proper decision making on response and rescue operation to reduce the number of causalities by increasing the number of promptly extracted people from the debris. The Committee on Data of the International Council for Science (CODATA) aims to act as an intermediary between organisations involved in data collection and those who use this data for earthquake loss model calibration. The CODATA task group was established to study the mechanism for connecting dispersed data to enable easier and faster discovery and access. FAIR-disaster risk reduction focused on addressing scientific questions, technical challenges, and best practices of disaster data management. Data Science has been used to merge with disaster research and response. Identification of geographical boundaries of the territory characterised by stable calibration parameters requires a significant increase in number of records about earthquake events and can be realised by the seismological community of the world combined under the CODATA umbrella. Simulated and observed intensities were compared for earthquakes in Croatia. The comparison of simulated and observed intensities shows that the calculated values of the intensities obtained within 20–30 min after the determination of the event almost coincide with the observed ones obtained from the responses of residents on the website of the Croatian Seismological Service and from the data of processing field observations.

3.11. Avoiding bias, assumptions, and data interpretations

Develop a plan to address any bias, assumptions, or interpretations by establishing protocols to monitor the data, providing regular training to keep skills of the user (mostly staff) accurate, and validating the risk assessment data. Also, elicit and enforce the FAIRness requirements early in the system design to allow clarifying the goals in relation to FAIRness.

4. Conclusions

Risk-informed data can be a useful tool to assess and analyse disasters and consequently improve the climate resilience of communities, people, and assets. Big data offers opportunities but also challenges. Countries with a lower gross domestic income are already adopting big data to be better prepared for climate disasters and its consequences. Moreover, technology and Artificial Intelligence (AI) approaches are developing rapidly, and the use of data is the way for the future. Going ahead we should focus on the following points to successfully harness risk-informed data to improve disaster and climate resilience:

- Data needs to be used according to the FAIR principle (FAIR Findable, Accessible, Interoperable and Reusable) and shall be open. Open data is data that anyone can use and share. Open data strategies are employed across the world in disaster-related data to provide information on the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 targets and indicators.
- Data mechanisms should be simplified to be able to collect, store and transfer data between different organisations and end-users easily. To enable this, increased technical and human capacity is required. Awareness has to be increased that biases might influence the modelling. Ethical considerations for this development will be essential
- Digital data collection is rather new and still not sufficiently widely available and accessible. For example, it would be valuable if historical data could be made accessible and stored in a centralised location. This additional data could help to observe trends and compare datasets.
- Many organisations and institutions collect data. It is crucial to support cooperation and partnerships between different institutions worldwide to ensure that as many users as possible gain access to data. Simply having access is often not sufficient, and efforts need to be undertaken to ensure timeliness and usability. This is important since disaster risk and climate resilience are complex topics that need to be seen in a broad context. Data can help to understand these connections, influences and impacts better.
- Risk needs to be understood as systematic, interconnected and cascading. Institutions and organisations worldwide should work toward developing a common definition of risk to ensure a comparable response, research and development process.
- Data have become more accessible with societal penetration of smartphones. Additional to the institutional data collection, a bottom-up approach should be followed, and the population and stakeholders have to be included in sensing, collecting experiences, and a more direct assessment and benefit of data in and for their environment. This is a crucial point to ensure growing databases.

The world is shifting from a "for-profit" to a "for-benefit" operating model [5,9]. Our stakeholders are our shareholders, employees, customers and more broadly the people and planet impacted by disasters climate change impacts. The challenges are evolving, and the opportunities continue to amplify. We could create a new socioeconomic era that closes historical gaps in the 'last mile inclusion' and engage the 'bottom billion' in a quantum leap for humanity and for a better planet. The world needs a Fifth Industrial Revolution to flower like a new Renaissance Age. It could be marked by creativity and a common purpose, as we should work together to support progress toward purpose and inclusivity for all.

Disclaimer

The article does not reflect the official views of the UN.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgement

The authors would like to thank Tonkin + Taylor in partnership with Integrated Research on Disaster Risk (IRDR), the Committee on Data (CODATA) of the ISC for organising the webinar and the WORLD-FAIR project of EU to review supports. DN acknowledges discussions with NASA CyGNSS project at the University of Texas at Austin. Thanks to Dr. Neeraj Shankar from Tonkin + Taylor for providing editorial support.

References

[1] Abdeen FN, Fernando T, Hettige S, Arjuna Ranasinghe K. Challenges in multi-agency collaboration in disaster management: a Sri Lankan perspective. Int J Disaster Risk Reduct 2021, August. https://doi.org/10.1016/j.ijdrr.2021.102399.

[2] Alizadeh T. Crowdsourced smart cities versus corporate smart cities. In: IOP Conference Series: Earth and Environmental Science. The 4th PlanoCosmo International Conference; 2018.

[3] Almutairi A, Mourshed M, Ameen RF. Coastal community resilience frameworks for disaster risk management. Nat Hazards 2020;595–630. https://doi.org/10.1007/s11069-020-03875-3.

[4] Auckland Council. Natural Hazard Risk Communication Toolbox. Auckland: Auckland Council; 2014. Retrieved 03 11, 2022, from, https://www.civildefence.govt.nz/assets/Uploads/NHRCToolbox/NHRCToolbox-Auckland-Council.pdf.

[5] Bapon Fakhruddin HC-G. Should I stay or should I go now? Why risk communication is the critical component in disaster risk reduction. Progress in Disaster Science; 2020.

[6] Berman M. Erosion vulnerability assessment (EVA) and planning tool. 2008.

[7] Bharosa N, Lee J, Janssen M. Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: propositions from field

exercises. Information Syst Front 2010;12:49–65. https://doi.org/10.1007/s10796-009-9174-z.
[9] Brown R, Pasquini L, Marie-AngeBaudoin.. Breaking down the silos: building resilience through cohesive and collaborative social networks. Environ Develop 2021;39. https://doi.org/10.1016/j.envdev.2021.100646.
[10] Carroll SR, Herczog E, Hudson M, et al. Operationalising the CARE and FAIR principles for indigenous data futures. Sci Data 2021;8:108. https://doi.org/10.1038/s41597-021-00892-0.
[11] Cinnamon J, Jones SK, Adger WN. Evidence and future potential of mobile phone data for disease disaster management. PubMed Central 2016:253–64.
[12] Cox S, Gonzalez-Beltran AN, Magagna B, Marinescu MC. Ten simple rules for making a vocabulary FAIR. PLoS Comput Biol 2021;17(6). https://doi.org/10.1371/journal.pcbi.1009041. e1009041.
[13] Digital Science, Fane B, Ayris P, Hahnel M, Hrynaszkiewicz I, Baynes G, et al. The state of open data report 2019. Digital Science. Report. 2019. https://doi.org/10.6084/m9.figshare.9980783.
[14] Ebrahimian A, Hashemi-Amrei S-H, Monesan M. Exploring factors affecting the emergency specialists' decision-making in case of emergencies in patients. Crtical Care Res Pract 2018, May 17. https://doi.org/10.1155/2018/9579807.
[15] Ebrahimian A, Hashemi-Amrei S-H, Monesan M. Exploring factors affecting the emergency specialists' decision-making in case of emergencies in patients. Crit Care Res Prac 2018, May 17. https://doi.org/10.1155/2018/9579807.
[17] Fakhruddin BAPON(SHM), Boylan Kate, Wild Alec, Robertson Rebekah. Chapter 12 - Assessing vulnerability and risk of climate change. In: Sillmann Jana, Sippel Sebastian, Russo Simone, editors. Climate extremes and their implications for impact and risk assessment. 2020. Elsevier; 2020. p. 217–41. ISBN 9780128148952.
[19] Gall M. The suitability of disaster loss databases to measure loss and damage from climate change. Int J Global Warm 2015:170–90.
[21] Geoscience Australia. Australian Government. Retrieved from Risk and Impact: https://www.ga.gov.au/scientific-topics/community-safety/risk-and-impact; 2021.
[25] IPCC. Climate Change 2014: Synthesis Report. In: Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland; 2014. p. 151.
[26] IPCC. IPCC sixth assessment report assesses the impacts of climate change. 2022.
[27] Liu Y, Chen J. Future global socioeconomic risk to droughts based on estimates of hazard, exposure, and vulnerability in a changing climate. In: Science of the total environment; 2021.
[28] Li T, Huang Y, Chen S-C. Data-driven techniques in disaster information management. ACM Computing Surveys 2017:1–45.
[29] McClain S, Kruczkiewicz A, Ndugwa R, Braneon C, Bader D, Bazo J, et al. Building risk-informed communities. In: Kavvada A, Cripe D, Friedl L, editors. Earth observation applications and global policy frameworks; 2022. https://doi.org/10.1002/9781119536789.ch7.
[31] Mizutori M, Hackmann H, Murray V. Launch of the UNDRR/ISC hazard information profiles: Supplement to UNDRR/ISC hazard definition & classification review: technical report (2020). Retrieved from, UNDRR; 2021, October 4. https://www.undrr.org/news/launch-undrr/isc-hazard-information-profiles-supplement-undrr/isc-hazard-definition.
[32] Morgan KM, Crawford A, Kowalcyk BB. Risk-based decision making definition: a scoping review of food, agricultural, environmental, and medical literature. Risk Anal 2022. https://doi.org/10.1111/risa.13845.
[33] Murnane RJ, Allegri G, Bushi A, Dabbeek J, Moel HD, Duncan M, et al. Data schemas for multiple hazards, exposure and vulnerability. Disaster Prevent Manag 2019;28(6):752–63. https://doi.org/10.1108/DPM-09-2019-0293. https://discovery.ucl.ac.uk/id/eprint/10086238/.
[34] Murray Virginia, Abrahams Jonathan, Abdallah Chadi, Ahmed Kanza, Angeles Lucille, Benouar Djillali, et al. Hazard Information Profiles: Supplement to UNDRR-ISC Hazard Definition & Classification Review: Technical Report: Geneva, Switzerland, United Nations Office for Disaster Risk Reduction; Paris, France, International Science Council. 2021. DOI: 10.24948/2021.05.
[35] Nirupama N. Risk and vulnerability assessment: a comprehensive approach. Int J Disaster Resilience Built Environ 2012;3(2):103–14. https://doi.org/10.1108/17595901211245189. https://www.emerald.com/insight/content/doi/10.1108/17595901211245189/full/html.
[37] O'Mahony C, Ferreira M, Fernández-Palacios Y, Haroun VC. Data availability and accessibility for sustainable tourism: an assessment involving different European coastal tourism destinations. J Coast Res 2009:1135–9.
[38] Osuteye E, Johnson C, Brown D. The data gap: an analysis of data availability on disaster losses in sub-Saharan African cities. Int J Disaster Risk Reduct 2017, December;26:24–33.
[39] Osuteye E, Johnson C, Brown D. The data gap: an analysis of data availability on disaster losses in sub-Saharan African cities. Int J Disaster Risk Reduct 2017, November 3. https://doi.org/10.1016/j.ijdrr.2017.09.026.
[40] Paelke V, Nebe K, Geiger C, Klompmaker F, Fischer H. Designing multi-modal map-based interfaces for disaster management. In: The fifth international conference on advances in computer-human interactions; 2012. p. 95–100. ProACHI 2012.
[41] Pagano P, Candela L, Castelli AD. Data interoperability. Data Sci J 2013;12. Retrieved from, https://www.jstage.jst.go.jp/article/dsj/12/0/12_GRDI-004/_pdf.
[42] Panwar V, Sen S. Disaster damage records of EM-DAT and DesInventar: a systematic comparison. Econ Disast Clim Change 2020;4:295–317. https://doi.org/10.1007/s41885-019-00052-0.
[43] Peng G, Lacagnina C, Downs RR, Ganske A, Ramapriyan HK, Ivánová I, et al. Global community guidelines for documenting, sharing, and reusing quality information of individual digital datasets. Data Sci J 2022;21(1):8. https://doi.org/10.5334/dsj-2022-008.
[44] Rani WN, Kamarudin KH, Razak KA, Hasan RC, Mohamad Z. Measuring Urban Resilience Using Climate Disaster Resilience Index (CDRI). International Conference on Geomatics and Geospatial Technology. Kuala Lumpur, Malaysia. 2018.
[45] Regional Assessment Report on Disaster Risk Reduction in the Arab States (RAR-Arab States). Chapter 4- Vulnerabilities and capacities in climate change mitigation and adaptation and disaster risk reduction: addressing structural drivers, impacts and empowerment of affected populations. https://www.undrr.org/2021-regional-assessment-report-arab-states; 2021.
[46] Saleki, M. A., Fanid, A. T., Valibeigi, M., & Ghasemi, M. (n.d.). Studying human-built factors on earthquake vulnerability in urban areas of Tabriz.
[47] Schipper L, Pelling M. Disaster risk, climate change and international development: scope for, and challenges to, integration. Disasters 2006:19–38.
[49] Sillmann J, Christensen I, Hochrainer-Stigler S, Huang-Lachmann J, Juhola S, Kornhuber K, et al. ISC-UNDRR-RISK KAN briefing note on systemic risk, Paris, France, International Science Council. 2022. DOI: 10.24948/2022.01.
[51] Stats NZ. Open data: Data that can spark and enable new ideas. Stats NZ: Retrieved from; 2018. https://www.stats.govt.nz/assets/Uploads/Data-leadership-fact-sheets/Fact-sheet-open-data-Mar-2018.pdf.
[53] Sukhwani V, Shaw R. Operationalising crowdsourcing through mobile applications for disaster management in India. Prog Disaster Sci 2020, January;5. https://doi.org/10.1016/j.pdisas.2019.100052.
[55] UNDRR. Sendai framework for disaster risk reduction 2015–2030. United Nations: Retrieved from; 2015. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.
[56] UNDRR. Terminology. Retrieved from United Nations Office for Disaster Risk Reduction: https://www.undrr.org/terminology; 2017.
[57] UNDRR. Disaster risk reduction and climate change adaptation in the UN sustainable development cooperation framework. Geneva: UNDRR; 2020.
[58] UNDRR. Analysis of DRR inclusion in National Climate Change Commitments. Geneva: UNDRR; 2021.
[60] United Nations. The 2030 agenda for sustainable development. United Nations: Department of Economic and Social Affairs; 2015. Retrieved from, https://sdgs.un.org/goals.
[61] University of Reading. Rescued Victorian rainfall data smashes former records. Retrieved from, https://www.reading.ac.uk/news/2022/Research-News/Rainfall-Rescue-records-publication; 2022, March 25.
[62] USIOTWS. How resilient is your coastal community? A guide for evaluating coastal community resilience to tsunamis and other hazards. USAID, NOAA, ADPC, The Nature Conservancy, USIOTWS, Coastal Resouce Center. Retrieved from, https://www.crc.uri.edu/download/CCRGuide_lowres.pdf; 2008.
[63] Valvis G, Polemi D. An XML-based data model for vulnerability assessment reports. Challenges of Expanding Internet: E-Commerce, E-Business, and E-Government; 2005. p. 513–26.
[74] Ye X, Niyogi D. Resilience of human settlements to climate change needs the convergence of urban planning and urban climate science. ComputUrban Sci 2022;2:6. https://doi.org/10.1007/s43762-022-00035-0.
[75] Yu H, Shen Z, Miao C, Leung C, Chen Y, Fauvel S, et al. A dataset of human decision-making in teamwork management. Scientific Data. Retrieved from, https://www.nature.com/articles/sdata2016127#citeas; 2017.
[77] OHDSI (2022). Data Standardization.https://www.ohdsi.org/data-standardization/Last accessed 20 September 2022.
[78] Fakhruddin, Bapon & Emma Singh (2022). Strengthening emergency communications for complex, cascading and compounding events – lessons learned from the Hunga Tonga-Hunga Ha'apai eruption and tsunami in Tonga. International Science Council (ISC). https://council.science/current/blog/emergency-communications-complex-cascading-events-lessons-eruption-and-tsunami-in-tonga/Last accessed 24 July 2022.
[79] Nagabhatla N, Cassidy-Neumiller M, Francine NN, Maatta N. Water, conflicts and migration and the role of regional diplomacy: Lake Chad, Congo Basin, and the Mbororo pastoralist. Environmental Science & Policy 2021;122:35–48. https://doi.org/10.1016/j. envsci.2021.03.019.
[80] AIDR. 2021. Systemic Disaster Risk Handbook, 1st edn. Melbourne, Australian Institute for Disaster Resilience. https://knowledge.aidr.org.au/resources/handbook-disaster-risk/ (Accessed 25 July 2022).
[81] Kontar, Y. Y., Ismail-Zadeh, A., Berkman, P. A., Duda, P. I., Gluckman, S. P., Kelman, I., et al. 2021. Knowledge exchange through science diplomacy to assist disaster risk reduction. Progress in Disaster Science, Vol. 11, 100188. doi: 10.1016/j.pdisas.2021.100188.
[82] Pielke Roger Jr., et al. Environ. Res. Lett. 17:024027. doi:10.1088/1748-9326/ac4ebf.
[83] Wilkinson M, Dumontier M, Aalbersberg I, et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 2016;3:160018. https://doi.org/10.1038/sdata.2016.18.
[84] IISD (2020). UNDRR Report Calls for Improved Governance to Address "Systemic Risk. International Institute for Sustainable Development. https://sdg.iisd.org/news/undrr-report-calls-for-improved-governance-to-address-systemic-risk/Last accessed 20 May 2020.
[85] Akter Shahriar & Samuel Fosso Wamba, 2019. "Big data and disaster management: a systematic review and agenda for future research," Annals of Operations Research, Springer, vol. 283(1), pages 939-959, December. DOI: 10.1007/s10479-017-2584-2.