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Data Tools for Assessing Disaster Risk Reduction: An Analysis of Literature Using Open-Access Disaster Risk Reduction Spatial Datasets to Implement the Sendai Framework

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Data tools for assessing disaster risk reduction: An analysis of literature using open-access disaster risk reduction spatial datasets to implement the Sendai Framework

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"Your dedication, expertise and guidance - in geospatial data, methods, frameworks, tools, and platforms - is urgently needed. The data needs for the SDGs are great, and time is not on our side. Reliable, timely, accessible and disaggregated geospatial information must be brought to bear to measure progress, inform decision-making and ensure effective and inclusive national and sub-national programs that will chart the path towards the 'Geospatial Way to a Better World', to assist in the implementation of the SDGs, and transform our world for the better."

António Guterres

Secretary-General of the United Nations

(video message to the United Nations World Geospatial Information Congress)

November 19th 2018

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Introduction

The first United Nations World Geospatial Information Congress (UNWGIC) convened in November of 2018 in Deqing, Zhejiang Province, China to discuss the importance and transformative role of geospatial information in understanding social, environmental, and economic issues that plague communities, and its potential for widespread application and use to ameliorate these issues (UN-GGIM, 2021). More than 2,000 participants gathered, representing governments, international organizations, civil societies, academia, and the private sector to strategize and envision how innovation and collaboration could discharge that year's conference theme: "The Geospatial Way to a Better World."

At the conclusion of the three-day conference, UNWGIC issued the Moganshan Declaration, a powerful acknowledgment, and call for action. The declaration acknowledged that geospatial technologies have been unequally adopted and, further, out of reach of many developing countries. It also recognized that geospatial technologies are essential to decision-making and delivery of services and projects critical to advancing the United Nations Sustainable Development Goals[1] (UN-GGIM, 2018). The call: work together, collaborate, and innovate across sectors, member states, knowledge, and technology to "stimulate global geospatial development progress (UN-GGIM, 2018, p3)."

Between 2000 and 2019, disasters claimed the lives of 1.23 million people, disrupted the lives of 4.2 billion, and caused US$2.97 trillion in economic damage (Mizutori & Guha-Sapir, 2020). As the human, social, and economic toll of disasters presents a serious challenge to achieving the UN's Sustainable Development Goals for many states, this study explores the use of geospatial information, specifically open-access spatial data, and the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030, a framework designed to manage disaster risk.

The priorities of the Sendai Framework are to (1) understand disaster risk; (2) strengthen disaster risk governance to manage risk; (3) invest in disaster risk reduction and resilience; and (4) enhance the capacity to recover from disasters (UNDRR, 2015). This study advances our knowledge of implementing the Sendai Framework from publications that have utilized open-access spatial data and issues common to Framework implementation. The findings from a literature review reveal that many of the problems cited by recent work are data-related. This study engages with these issues and discusses how they could be addressed by those who have a vested interest in disaster risk reduction, from policymakers to community members.

[1] The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, yielded 17 goals: no poverty; zero hunger; good health and wellbeing; quality education; gender equality, clear water and sanitation, affordable and clean energy, decent work and economic growth; industry, innovation, and infrastructure; reduced inequalities; sustainable communities; responsible consumption; climate action; life below water; life on land; peace, justice, and strong institutions; and partnerships for the goals. Visit https://sdgs.un.org/goals to learn more.

The Sendai Framework

Adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan on March 18th, 2015, the Sendai Framework represents a global effort to substantially reduce disaster risk and stem the tide of increasing losses to natural hazards. The Sendai Framework follows the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disaster ("HFA"), the founding document of the World Conference on Disaster Reduction in 2005. The HFA had 153 signatories, countries committed to implementing the HFA through institutionalization, monitoring, public awareness, reducing risk, and strengthening preparedness. Ten years later, the efforts of the HFA were formalized, once again, in the ambitious goals of the Sendai Framework; to reduce global disaster mortality; reduce the number of affected people; reduce direct disaster economic loss; reduce disaster damage to critical infrastructure and disruption of basic service; increase the number of countries with risk reduction strategies; enhance international cooperation; and increase the availability of and access to early warning systems.

At the onset of adopting the Sendai Framework, the Information and Knowledge Management for Disaster Risk Reduction (IKM4DRR) community found that special attention was needed to generate and sustain information and knowledge at all levels in order to make informed decision-making and progress toward the goals of the Sendai Framework. In a 2013 (UNISDR, 2013) report, the IKM4DRR outlined the following principles for effective knowledge and information generation and management: demand-driven, standards-based, collaborative, sustainable, transparent, and monitored. A report from the 2015 Global Assessment Report (Duncan et al., 2014) released the following year identified recommendations, such as common information architecture, improving the comparability of existing loss databases, harmonization of terminology, and the development of interoperable information systems.

Several open-access disaster risk reduction spatial datasets and systems, such as the Disaster Inventory System (DesInventar), Emergency Events Database (EM-DAT), and the Global Assessment Report (GAR) Risk Data Platform, among others, provide researchers and practitioners access to data to measure progress toward achieving disaster risk reduction goals.

Motivation

This study explores how researchers have, to date, used open-access spatial disaster risk reduction data sources to assess progress toward the goals of the Sendai Framework and identifies the common barriers to achieving said goals. More specifically, it examines the literature that uses open-access disaster risk reduction spatial datasets that discuss the implementation of the Sendai Framework ("the Framework"). The discussion presents potential solutions to the implementation challenges cited in the literature reviewed in this paper. The review of literature is carried out by identifying the publications that, first, use the georeferenced disaster risk reduction datasets, and then more specifically, narrows the search to publications that speak directly to the implementation or application of the Framework. The findings of the analysis identify how nation-states have thus far made progress toward achieving the Sendai goals and provides action-orientated recommendations for practitioners who encounter regular challenges to implementation.

The primary motivation of this study is to identify how states have thus far made progress toward achieving the Sendai goals based on analyses that use open-access spatial data, and further, identify some of the common issues and their potential solutions discussed in the literature, many of which are data-related. The goal of this research is to demonstrate how actors have engaged in productive and meaningful ways to mitigate disaster risk, but also to identify barriers to achieving or even accurately measuring progress to the goals of the Framework.

The findings from this study reveal that facilitating regional interaction frameworks, engaging community members, educating post-disaster workers, and implementing mitigation and preparation plans have given states some measurable progress toward implementing the Sendai goals. Data quality and integrity, lack of resources and infrastructure, lack of political leadership or political corruption, and inconsistent standards with definitions and data collections are some of the challenges cited by researchers studying the implementation of the Framework with open-access spatial data. Further discussion of these barriers and how practitioners and researchers can address them takes place in the **Discussion** section.

Open-access spatial data

In this paper, open-access spatial data refers to spatial data that is "freely accessible, shareable, and usable (Coetzee et al., 2020, p2)." Unlike freely available data, data from the Munich Re's NatCatSERVICE[2] often used in hazards research is an example of data excluded from this category, as users must pay to access the data. Open-access data is not limited to datasets; it can also include open-access software, hardware, standards, education, journals, and science (Coetzee et al., 2020). There are three open-access data categories: crowdsourced data, authoritative data, and scientific data (Coetzee et al., 2020).

Crowdsourced data refers to geospatial data created and maintained by volunteers, often organized on platforms such as OpenStreetMap. This data is a result of participatory, bottom-up mapping initiatives. For example, citizens in Japan took regular radiation measurements near the Fukushima Daiichi Nuclear Power Plant following the March 11th, 2011 Triple Disaster. Policymakers and experts used this mapped data to address community health and safety concerns (Brown et al., 2016).

Authoritative data is collected and published by official agencies and administrations, published "in the spirit of freedom of access to information (Coetzee et al., 2020, p12)." For example, EM-DAT (Guha-Sapir et al., 2021), managed by the Centre for Research on the Epidemiology of Disasters at the Université Catholique de Louvain, is the leading international disasters database. Their open-access data has resulted in thousands of publications offering insights into the impacts of small- and large-scale disasters alike.

The third kind of geospatial data is *open-scientific* geospatial data. This data is available when researchers publish their data as supplemental material to their published journal article to allow others in the scientific community to confirm or reject their claims and findings. This data is often found in open and FAIR (findable, accessible, interoperable, and reusable) scientific data repositories, such as the Harvard Dataverse[3], openICPSR[4], Open Science Framework[5], Qualitative Data Repository[6], and the UK Data Service[7]. This study focuses exclusively on

[2] https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html
[3] https://dataverse.harvard.edu/
[4] https://www.openicpsr.org/openicpsr/
[5] https://osf.io/
[6] https://qdr.syr.edu/
[7] https://ukdataservice.ac.uk/

open-access authoritative spatial data to understand how open-access spatial data has been used to assess the implementation or application of the Sendai Framework and the challenges and lessons that have emerged from the literature.

There are databases and data platforms that provide open-access spatial data to study disasters and hazards, and specifically, the implementation of the Sendai Framework. A database system is "a computerized record-keeping system with the overall purpose of maintaining information and making it available whenever required. The database typically stores related data in a computer system (Foster, Godbole, & Shripad, 2014, Chapter 1)." Data platforms are collections of datasets or databases. Examples include GED4GEM[8], PCRAFI[9], SEDAC[10], Global Forest Watch Data Platform[11], Aqueduct Data Platform[12], Resource Watch Data Platform[13], Climate Watch Data Platform[14], Energy Access Explorer Data Platform[15], and the Landmark Data Platform[16].

This study explores the literature that uses common hazard and disaster database systems, including Canadian Disaster Database[17], ANSS Comprehensive Earthquake Catalog (ComCat)[18], Disaster Inventory System (DesInventar)[19], Emergency Events Database (EM-DAT)[20], Global Assessment Report (GAR) Risk Data Platform[21], Global Integrated Drought Monitoring and Prediction System (GIDMaPS) [22], Global Centroid-Moment-Tensor (CMT) Database[23], Hurricane Satellite (HURSAT) data[24], International Best Track Archive for Climate Stewardship (IBTrACS) data[25], and the Global Internal Displacement Database (iDMC) Database[26]. Table 1 displays the following characteristics of the databases: the source of institutional support to maintain and host the database, the hazard(s) featured in the database, and the export options available from the website hosting the database.

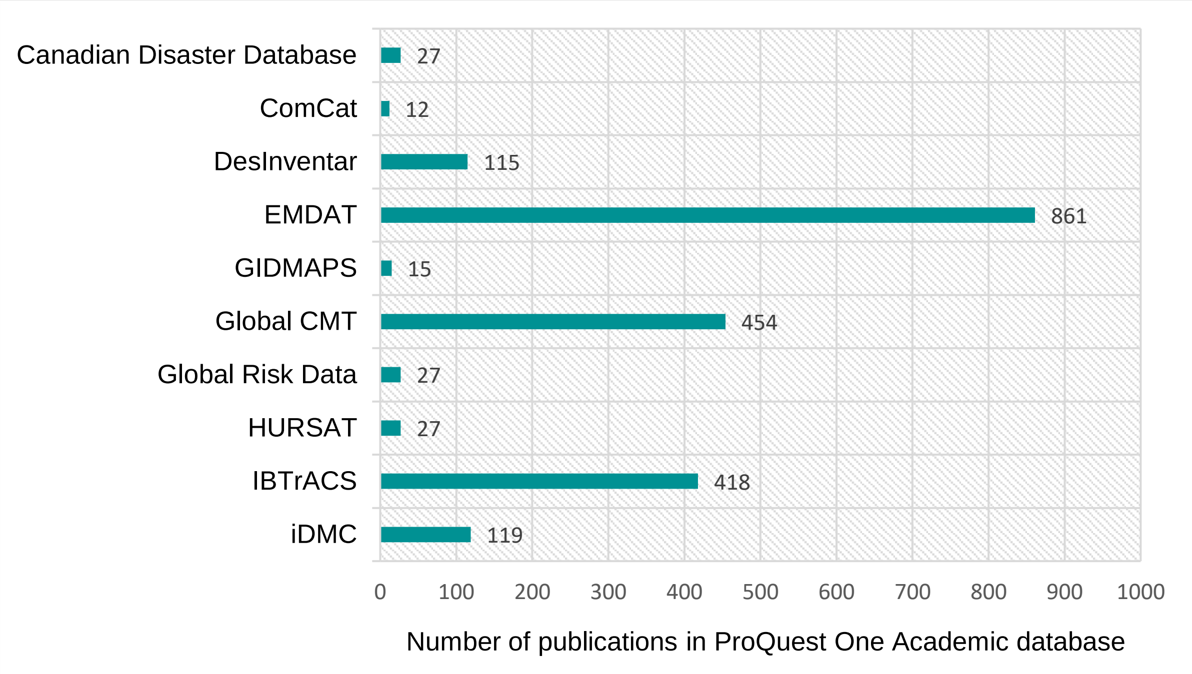
8 https://storage.globalquakemodel.org/resources/use-and-share/data/
9 http://pcrafi.spc.int/
10 https://sedac.ciesin.columbia.edu/data/collection/ndh
11 https://www.globalforestwatch.org/
12 https://www.wri.org/resources/maps/aqueduct-global-flood-analyzer
13 https://resourcewatch.org/
14 https://www.climatewatchdata.org/
15 https://www.energyaccessexplorer.org/
16 http://www.landmarkmap.org/
17 https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx
18 https://earthquake.usgs.gov/data/comcat/
19 https://www.desinventar.net/
20 https://www.emdat.be/
21 https://preview.grid.unep.ch/
22 http://drought.eng.uci.edu/
23 https://www.globalcmt.org/CMTsearch.html
24 https://www.ncdc.noaa.gov/hursat/
25 https://www.ncdc.noaa.gov/ibtracs/
26 https://www.internal-displacement.org/

Table 1. Open-Access Spatial Databases

Database	Support	Hazard	Export Options
Canadian Disaster Database	Government of Canada	Multiple	.txt, .kml
ComCat	U.S. Geological Survey (USGS)	Earthquakes	.csv, .kml, .quakeml, geojson
DesInventar	United Nations Office for Disaster Risk Reduction (UNDRR)	Multiple	.xls, .csv
EM-DAT	Centre for Research on the Epidemiology of Disasters	Multiple	.xls, .csv
GAR Risk Data Platform	United Nations Office for Disaster Risk Reduction (UNDRR)	Multiple	.csv, shapefile, GeoTiff
GIDMaPS	Hydroclimate Research Lab, University of California, Irvine	Drought	.png
Global CMT	National Science Foundation	Earthquakes	.ndk
HURSAT	NOAA	Tropical Cyclones	.netCDF, .kml
IBTrACS	NOAA	Cyclones	.netCDF, .csv, shapefile
iDMC Database	Internal Displacement Monitoring Centre	Multiple	.xls

An initial search of the databases using the ProQuest One Academic research database resulted in 2,696 records. After removing duplicates, 2,102 records remained. This broad overview of the articles displays general usage of the databases and that DesInventar, EM-DAT, Global CMT, IBTrACS, and iDMC are the most cited databases used in hazard research articles on the ProQuest database. The EM-DAT database accounts for 41% of the records, followed by the Global CMT database (22%), IBTrACS (20%), iDMC (6%), DesInventar (5%), with the Canadian Disaster Database, ComCat, GIDMAPS, and HURSAT accounting for the remaining 6%. The distribution of articles by database is displayed in Figure 1.

Figure 1. Articles in ProQuest One Academic research database by Open-Access Spatial Database

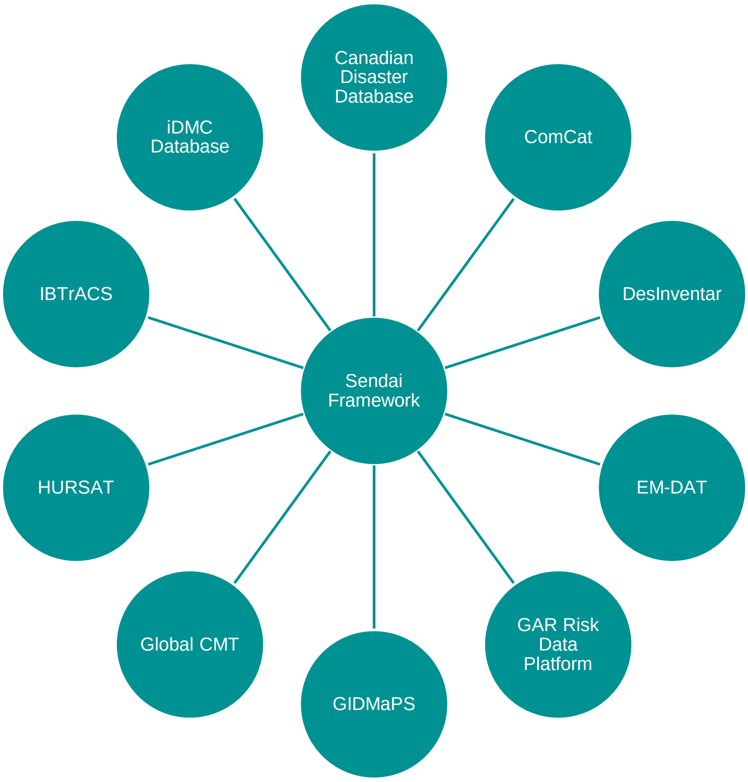


Method

To identify relevant literature for this review, this study employed a search strategy to identify publications that used open-access disaster risk reduction spatial datasets to study the implementation of the Sendai Framework. To do so, ten separate searches were implemented on the ProQuest database for each open-access spatial disaster risk reduction dataset. Canadian Disaster Database, ComCat, DesInventar, EM-DAT, GAR Risk Data Platform, GIDMaPS, Global CMT, HURSAT, IBTrACS, and the iDMC Database were included in the search.

Each search used an exact phrase (e.g., "DesInventar," "EM-DAT") with quotes to search the open-access disaster risk reduction spatial dataset and the Sendai Framework (e.g., "Sendai Framework"). A Boolean operator "AND" was used between the open-access disaster risk reduction spatial dataset and the Sendai Framework (e.g., "EM-DAT" AND "Sendai Framework") to require that both terms appear in the publications. A filter was applied to each search to limit the results to the following criteria: Limit to == Peer reviewed, Source type: == Scholarly journals, and Language == English. Figure 2 visualizes the search terms used in the search strategy.

Figure 2. Radial Venn diagram of literature review search terms



Findings

This study includes a review of literature from the ProQuest database to identify peer-reviewed publications that used open-access spatial data to assess the implementation of the Sendai Framework (Figure 3 visualizes the inclusion process). After searching the database name with the Boolean operator "AND" to include the "Sendai Framework," the initial results from the search produced 146 records. The total record count dropped to 114 after removing duplicate articles from the search. Further screening included searching for the term "Sendai" in the abstract, removing 93 records from the search. The remaining 21 articles were screened for eligibility, resulting in the exclusion of seven articles. The seven articles excluded from the results were not directly related to the implementation or assessment of the Sendai Framework, rather, they mentioned the Framework only tangentially or failed to utilize spatial data. This review resulted in a total of 14 articles included and analyzed in this study (see Table 2 in Annex for a record of articles included in the review, organized by the spatial database).

A limitation of this search strategy excludes publications not found on the ProQuest database; however, additional research was conducted to expand on the findings from this review.

Figure 3. Flow chart of the review process

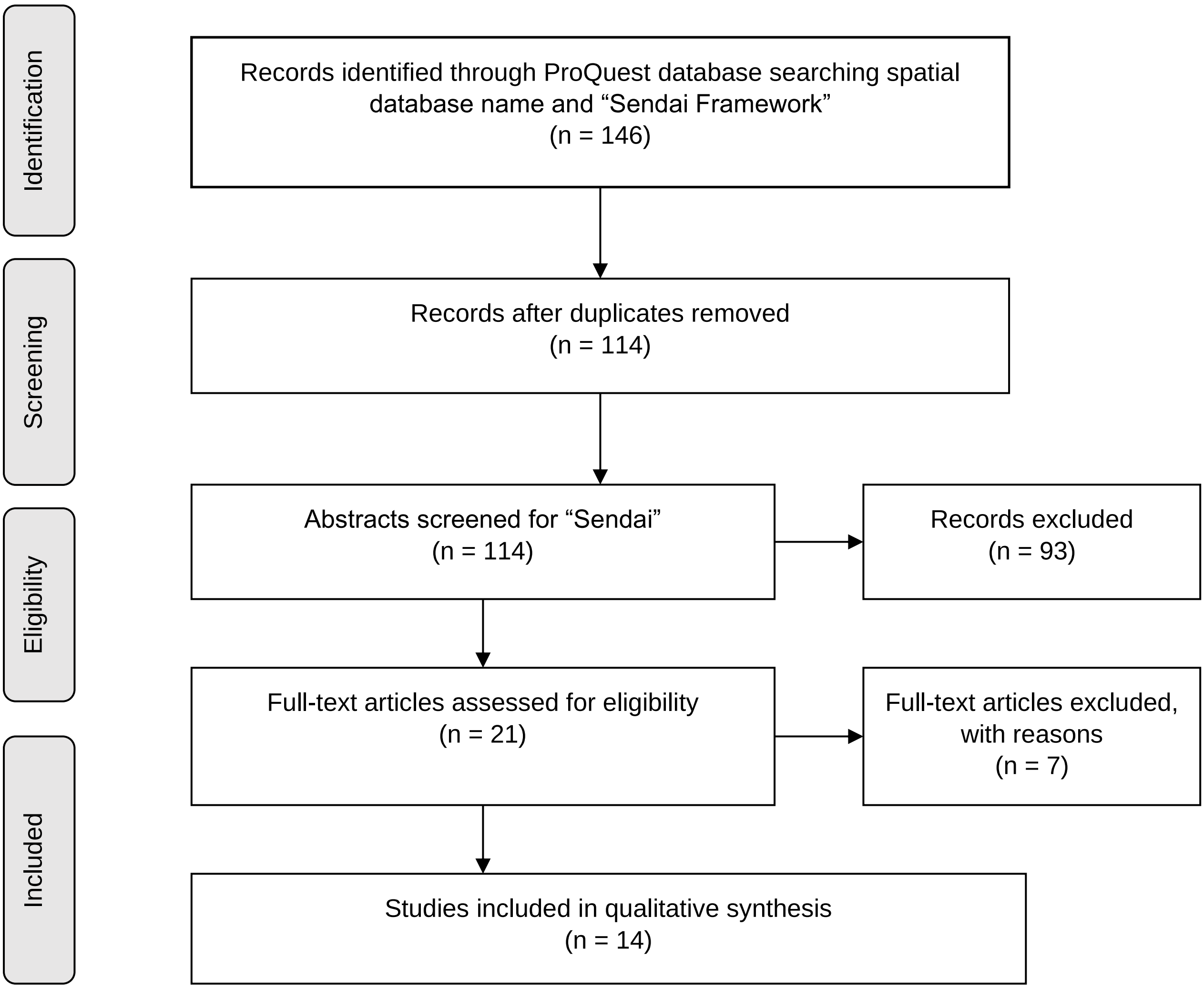


Diagram template adapted from Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097.

As a result of the review of the literature, the findings of this study suggest that the current literature that uses open-access spatial data to assess the implementation of the Sendai Framework, in general, discusses the opportunities and common barriers to achieving the goals of the Framework. The findings of this analysis follow in two sections: examples of what states are doing to achieve the Framework's goals and the challenges to substantially achieving the Framework's goals.

Progress Toward Implementing the Sendai Framework

Results from current studies suggest that states have engaged in productive and meaningful ways to mitigate disaster risk, such as: facilitating regional interaction frameworks; engaging and empowering community members; training and educating post-disaster workers; and implementing mitigation and preparation plans.

In an in-depth assessment of Guatemala (Gill et al., 2020), researchers suggested comprehensive, systematic, and evidenced regional interaction frameworks as the first step to understanding the complexity of multi-hazard landscapes. Using evidence from international literature, civil protection bulletins, field observations, stakeholder interviews, and workshops, researchers constructed a regional interactions framework, including national and sub-national actors, like the Guatemalan Highlands. The result of this framework yielded a unified and formal structure that allows for expert knowledge at the local level and is scalable and reproducible at different scales and geographies to monitor and assess risk-reduction strategies, communications, and collaboration mechanisms.

In Chile, the local government organized a series of events to recapture the fading memory of a catastrophic tsunami that occurred in Valparaíso in 1730, inviting participation from politicians, scholars, and members of the local community to start a discussion of risk mitigation to future hazards to achieve the goals of the Framework (Zamora et al., 2020). This event was important to raise awareness of risk, but also to dispel local narratives claiming the invulnerable nature of the Valparaíso area. Local narratives induced a moral hazard for individuals, claiming that the shape and depth of the Valparaíso Bay served as a natural barrier to tsunamis. To engage community members, researchers organized educational material adapted for different ages and in different mediums. Information was distributed in brochures, interactive activities, handouts, and mobile earthquake simulators.

In an analysis of synergies across the Sendai Framework 2015-2030, Paris Climate Change Agreement 2015 (COP21), and the UN Sustainable Development Goals, some researchers have underscored the importance of facilitating education for built environment professionals (Perera et al., 2018). Post-disaster reconstruction has been referred to as a process that is both resource-consuming and complex, and further education around knowledge areas of teamwork; budgeting; financial planning; leadership; people management; communication; negotiation; information systems; insurance; audits and reporting; business planning; and multi-stakeholder management can potentially make disaster management a more sustainable process. Further education of built environment professionals has the potential to ensure availability of water, sanitation, and affordable energy; build resilient physical infrastructure that can also promote innovation; promote community designs that are inclusive, sustainable, and safe; and encourage action around climate change and revitalization.

In a study using the Canadian Disaster Database, researchers studying Canadian hazard trends (Godsoe et al., 2019) found that for Canada to meet the ambitious goals of the Framework with forecasted increases of disasters, the Canadian government must take calculated actions to mitigate future losses. To protect affected communities, they recommended that disaster planners should implement mitigation and preparation plans to keep 88 hazard events from developing into disasters; that planning and mitigation efforts must prevent 4,712 disaster-related injuries from occurring and 555,826 evacuations from taking place; and that loss prevention should avoid $92.1 billion in losses from disasters. Despite the support from political leadership and new programming to support disaster risk-reduction, authors found it unlikely that Canada will achieve the baseline goals outlined by the Sendai Framework.

Finally, in a study of 30 disaster managers from Oceania (Cuthbertson et al., 2019), researchers identified several environmental (i.e., heat, climate change, rising sea levels) and developmental (i.e., population changes, urbanization, transportation) issues as broader challenges to implementation, and also decried top-down approaches to disaster risk reduction. Individuals interviewed often referred to a disharmony between the needs of individuals affected by risk and the policies designed to mitigate their risk. Respondents agreed that by giving individuals risk ownership, leadership, and the agency to act by minimizing top-down approaches, communities were better prepared to confront current challenges. Similarly, in another study, researchers advocated for empowering youth to co-create plans that would mitigate risk in Canada (Cox et al., 2019).

Common Obstacles to Implementing the Sendai Framework

Reducing losses to disasters presents a series of unique challenges presented by researchers. Some of the common obstacles to achieving the goals of the Sendai Framework mentioned in the current literature include lack of quality (van Niekerk Dewald et al., 2020) and consistent data across categories and time (Godsoe et al., 2019); the inability of some countries to properly monitor key measures (Koç et al., 2018); incompatible data standards (Migliorini et al., 2019); a lack of a universal classification of disasters (Maini et al., 2017); and a lack of political and poor governance structures, leading to inconsistent risk reduction strategies (Cuthbertson et al., 2019).

Some have identified conditions such as low per capita GDP and high multi-hazard intensity as significant obstacles to reducing risk and loss in countries and regions around the Pacific and Indian Oceans (Shi et al., 2016). Researchers (Green et al., 2019) have cited issues with accurately measuring and monitoring a significant reduction in disaster mortality, namely problems with robust estimates of baseline mortality rates occurring before the Sendai Framework from 2005-2015 in some countries; incomparable data on cause of death and timeframes of hazard impact across countries; and realization that registering mortality data can be severely delayed and occur several months or even years after a disaster, all of which can prevent accurate measurements of disasters that can span several years.

Findings from a survey (Migliorini et al., 2019) of 56 individuals representative of the public, private, academic, and non-profit sectors identified the following challenges in implementing the Framework: coordination and cooperation across sectors and industries; technical issues with data software and emergency management systems; issues with standardized data collection protocols; and accessibility and interpretability of data collected. In a case study of Cameroon, authors cite lack of proper communication structures; arduous administrative vetting processes; lack of local knowledge and skilled disaster managers; insufficient budgets and legislative backing; routine embezzlement and corruption of the few resources available; poor cross-sector coordination; and compliance issues that prevent the advancement of sustainable development (Bang et al., 2019). In a continent-wide study (van Niekerk et al., 2020) examining Africa's progress toward the Sendai goals, researchers found that while some progress has been made, action is still needed to improve reporting as drought-related deaths remain largely unreported in African countries.

Further, to reach the goal of substantially reducing disaster risk and loss, researchers have urged that innovative approaches and partnerships are required to reduce excess deaths resulting from environmental contaminants that are unavoidable in some countries. For example, in a study (Finnigan 2019) of large-scale fires that originated in Sumatra and Kalimantan, Indonesia that occurred between June and October of 2015, it was found that an excess of 2.6 million hectares of forest, peat, and other land burned, producing a thick of haze of smoke that was picked up and carried by winds to neighboring countries. Estimated to have affected nearly 185 million people, models have predicted from 11,880 to 103,000 excess deaths in the region from exposure to the thick haze of smoke. When the source of the hazard cannot otherwise be mitigated for many of those affected, innovation and partnerships, such as integrating surveillance of weather and climate and health care information systems, may offer a way to mitigate these risks.

Discussion

This study reveals the current progress and limitations towards achieving the goals of the Sendai Framework. This review includes scientific research that relied on open-access authoritative spatial data and represents a small percentage of research using open-access authoritative spatial data.

In general, there are cases of progress toward achieving the Sendai goals. Examples of progress toward implementation include facilitating regional interaction frameworks; inviting politicians, scholars, and members of the local community to capture a fading memory of a previous catastrophe to spark a conversation of future resilience; developing a curriculum to educate built environment professionals to rethink how built structures can be inclusive, sustainable, and safe for future generations; analyzing historical data trends to inform planning and mitigation efforts to reduce future losses; and empowering individuals with leadership and co-creating plans with the next generation.

Researchers studying the implementation of the Sendai Framework also identified a host of obstacles to success, many of which are related to data collection and management. Issues with data quality and integrity; lack of resources and infrastructure; lack of political leadership or political corruption; and inconsistent standards with definitions and data collections are some common issues identified across the literature in this review. To make measurable success on the Sendai goals, stakeholders should consider their own capacity to address these barriers. The remainder of this section discusses the challenges revealed in the review and potential solutions.

Data Quality

Quality data is a necessary precondition for meaningful analyses and has important implications for measuring the progress of implementation of the Sendai Framework. For example, a recent publication on post-disaster supply chain and critical infrastructure restoration illustrated several challenges across all the data necessary to generate an integrated supply chain interdependent critical infrastructure system (SCICI) model. Issues included: static data; generalized data; proprietary data; data inconsistency; software requirements; ownership of data; differing temporary factors of data; and scalability issues (Ramachandran et al., 2016).

Recent advances in data quality and integrity offer researchers and practitioners a framework for assessing or achieving both. Based on Cai and Zhu's Hierarchical big data quality assessment framework (2015), the five dimensions of data quality include availability, usability, reliability, relevance, and presentation quality. Availability includes accessibility and timeliness; whether the data have an accessible interface, the data can be easily accessed (either made public or for purchase), and if the data are regularly updated. Usability refers to the credibility of the data, assessed by the credentials of the producer of the data and the degree to which they possess specialized knowledge to generate the data; that the data are presented in known values; and that there is external validation from subject-matter experts who audit the data for correctness. Measures of reliability include data accuracy, consistency, integrity, and completeness. Relevance of the data is assessed by its fitness, or rather, that the datasets retrieved match the needs of the user based on their query. Finally, presentation quality includes the readability of the data; that the data are clear, and the user can quickly determine the data meets their needs based on the data description, classification, and coding.

Lack of resources and infrastructure

Lack of resources and infrastructure have been common themes in data science and disaster risk reduction. For developing countries, lack of reliable infrastructure and expertise are often cited as barriers to collecting and leveraging open data (Anokwa et al., 2009). Further, developed countries are not immune to issues of unreliable or insufficient resources. At the "Rescue of Data at Risk" workshop held in Boulder, Colorado in September of 2016, participants cited the lack of funding and personnel, natural and political disasters, and metadata loss as some of the greatest threats[27] to data collection (Mayernik et al., 2020). Platforms like the National Institute of Standards and Technology (NIST) Open Access to Research (OAR) scientific data infrastructure (Greene et al., 2019) and The Data Integration and Analysis System (DIAS)[28] (Kawasaki et al., 2017)[29] offer data systems that have the potential to facilitate infrastructure and metadata data management needs, especially in many developing countries.

The overarching goal of the NIST OAR[30] is to involve "collaborative data science (Greene et al., 2019)." The platform was first initiated in 2015 and then launched in 2017 using open-source software documented in Github repositories[31]. The platform is expected to foster research among national and international scientific collaborations, such as the Research Data Alliance and CODATA organizations. Further, it offers an infrastructure for professionals and scientists to share research data based on standards and practices adopted by those in their respective scientific communities.

The DIAS is a platform first conceived in 2006 and supported by the government of Japan. It has since been implemented and collects data from sources such as satellites, weather stations, and weather prediction models; integrates the data into its ecosystem with related human and environmental indicators; and generates results that can be used for reducing disaster risk (Kawasaki et al., 2017). The platform facilitates cooperation and collaboration across multiple stakeholders and enables transdisciplinary research with its platform and metadata management system (Kawasaki et al., 2018).

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[27] Note: A comprehensive list of risk factors for data collection (Mayernik et al., 2020, p.5) include: lack of use, loss of funding for archive, loss of funding for specific datasets, loss of knowledge around context or access, lack of documentation and metadata, data mislabeling, catastrophes, poor data governance, legal status of ownership and use, media deterioration, missing files, dependence on server provider, accidental deletion, lack of planning, cybersecurity breach, over-abundance, political inferences, lack of provenance information, file format obsolescence, storage hardware breakdown, and bit rot and data corruption.

[28] https://diasjp.net/en/about/

[29] Note: A similar platform also includes The Integrated Information System for Natural Disaster Mitigation (Wu et al., 2007), once supported by the World Bank, but never realized.

[30] https://data.nist.gov/sdp/#/

[31] Github is a website dedicated to building, developing, and maintaining open-source software and its source code. To learn more about the NIST OAR open-source software, visit https://github.com/usnistgov/oar-sdp.

Further, governments should consider expanding available resources by working with academia and international organizations to unify and coordinate their efforts and promote interconnection; consult relevant agencies at every scale, from national agencies to communities to establish copyright protection and terms of acceptable use in order to mitigate the impacts of disasters; and consider pilot projects that make use of cross-disciplinary and cross-sector approaches, such as academic experiments with the goal of further understanding disaster risk reduction (Li et al., 2019). Further, the international community should continue to support the development of mechanisms of cooperation and basic data infrastructure in developing countries (Li et al., 2019).

Lack of political leadership and political corruption

To address the challenges of political corruption and the lack of political leadership, international organizations should continue to promote platforms that empower individuals and communities to become producers and co-producers of data. Ushahidi, a not-for-profit technology company that initially emerged in 2008, offered a tool for Kenyan citizens to map and crowdsource information related to the violence taking place after former President Mwai Kibaki was declared the winner (Ushahidi, 2021). The Ushahidi platform has since grown to be a global crisis tracking platform. For example, after the January 12th, 2010 earthquake in Haiti, the platform helped organize response in the early days of the disaster by offering real-time, mapped information to NGOs and privately funded organizations (Morrow et al., 2011). As of 2021, the platform boasts 200,000 deployments, 50 million posts, and has reached 25 million people in a crisis (Ushahidi, 2021). Platforms like Ushahidi offer a tool that can be harnessed by individuals and communities to use data to mitigate their risk to future hazards despite political corruption and the lack of political leadership that can hamper risk reduction and resilience.

Inconsistent standards with definitions and data collection

Finally, to address issues of inconsistent standards with definitions and data collection, practitioners and researchers should continue to use the industry-standard disaster risk reduction guidelines outlined in the Next Generation Disaster Data Infrastructure report (2019), such as the IRDR Peril Classification[32], Data Collection Protocol presented in the 5th GP-DRR in 2017[33], FEMA National Disaster Recovery Framework[34], the WHO classification and minimum standards for foreign medical teams in sudden-onset disasters[35], JRC Guidance for Recording and Sharing Disaster Damage and Loss of Data[36], and requirements from CoreTrustSeal[37], among others[38].

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32 https://www.preventionweb.net/publications/view/36979

33 Note: See the Disaster Loss Data: Raising the Standard white paper published in 2017 by Tonkin+Taylor, IRDR, and CODATA

34 https://www.fema.gov/emergency-managers/national-preparedness/frameworks/recovery

35 https://cdn.who.int/media/docs/default-source/documents/publications/classification-and-minimum-standards-for-foreign-medical-teams-in-suddent-onset-disasters65829584-c349-4f98-b828-f2ffff4fe089.pdf?sfvrsn=43a8b2f1_1

36 https://publications.jrc.ec.europa.eu/repository/handle/JRC95505

37 https://www.coretrustseal.org/

38 Note: See Examples of disaster related standards and guidelines in the *Next Generation Disaster Data Infrastructure* (2019) report for an exhaustive list with standard category, name, organization, scope, and URL.

Further, key opportunities for enhancing the use of standardized terminology and a standardized format of data collection include improving partnerships between insurance companies, government agencies, academic institutions, NGOs, and the private sector; capacity building with the Sendai Framework Monitor online tool[39]; data interoperability; standardized disaster loss data quantification; and resource mobilization to support the improvement of data reporting at all levels (Fakhruddin et al., 2019).

[39] https://sendaimonitor.undrr.org/

Conclusion

Open-access spatial data presents incredible opportunities for assessments and innovation; to improve public services; advance our shared understanding; and offer tools and capacity that developing countries may not otherwise have (Coetzee et al., 2020). This study reveals that the literature using open-access spatial data to study the implementation of the Sendai Framework cites real progress toward its goals. Examples include regional interaction frameworks; individual empowerment; innovative training and education for built environment professionals; and analysis of historical data trends to inform future planning and mitigation efforts. However, as we move toward more measurable outcomes of the Sendai Framework, the findings from this review reveal that ensuring uniform standards; shared definitions; improved data quality; additional resources and infrastructure; and bottom-up approaches will be key to assessing implementation and progress toward the Sendai Framework.

To address issues of data quality and integrity; lack of resources and infrastructure; lack of political leadership or political corruption; and inconsistent standards with definitions and data collection, we must heed the call from the Moganshan Declaration to work together, collaborate, and innovate across sectors, member states, knowledge, and technology to achieve risk reduction and resilience.

Annex

Table 2. Articles included in review of literature, by database

Database	Title	Authors
Canadian Disaster Database	More than a checkbox: engaging youth in disaster risk reduction and resilience in Canada	Cox et al., 2019
Canadian Disaster Database	Assessing Canada's disaster baselines and projections under the Sendai Framework for Disaster Risk Reduction: a modeling tool to track progress	Godsoe et al., 2019
Comcat	The 1730 Great Metropolitan Chile Earthquake and Tsunami Commemoration: Joint Efforts to Increase the Country's Awareness	Zamora et al., 2020
DesInventar	Construction of regional multi-hazard interaction frameworks, with an application to Guatemala	Gill et al., 2020
DesInventar	Challenges with Disaster Mortality Data and Measuring Progress Towards the Implementation of the Sendai Framework	Green et al., 2019
DesInventar	The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss databases?	Koç et al., 2018
DesInventar	Data interoperability for disaster risk reduction in Europe	Migliorini et al., 2019
DesInventar	Implementing the Sendai Framework in Africa: Progress Against the Targets (2015–2018)	van Niekerk Dewald et al., 2020
EM-DAT	Disaster Risk Reduction in Cameroon: Are Contemporary Disaster Management Frameworks Accommodating the Sendai Framework Agenda 2030?	Bang et al., 2019
EM-DAT	Current and Emerging Disaster Risks Perceptions in Oceania: Key Stakeholders Recommendations for Disaster Management and Resilience Building	Cuthbertson et al., 2019
EM-DAT	The natural environment as a disaster hazard	Finnigan 2019
EM-DAT	The Sendai Framework for Disaster Risk Reduction and Its Indicators--Where Does Health Fit in?	Maini et al., 2017
EM-DAT	Mapping built environment professionals' educational needs to international policy frameworks for disaster risk reduction – community stakeholder perspective	Perera et al., 2018
EM-DAT	Mapping Global Mortality and Affected Population Risks for Multiple Natural Hazards	Shi et al., 2016

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