International Journal of Disaster Risk Reduction 47 (2020) 101638

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: http://www.elsevier.com/locate/ijdrr

Developing a geographic information capacity (GIC) profile for disaster risk management under United Nations framework commitments

Brian M. Tomaszewski [a,*], Elizabeth A. Moore [b], Kyle Parnell [b,1], Alexandra M. Leader [b,1], William R. Armington [b,1], Omar Aponte [h,1], Leslie Brooks [b,1], Brienna K. Herold [g,1], Benjamin S. Meyers [g,1], Tayler Ruggero [a,1], Zachary Sutherby [a,1], Madeline Wolters [c], Sandy Wu [a], Jörg Szarzynski [d,i], Klaus Greve [e], Robert Parody [f]

[a] Center for Geographic Information Science & Technology, Rochester Institute of Technology, Rochester, NY, USA
[b] Golisano Institute for Sustainability, Rochester Institute of Technology, Rochester, NY, USA
[c] Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, Rochester, NY, USA
[d] United Nations University Institute for Environment and Human Security (UNU-EHS), Bonn, Germany
[e] Department of Geography, University of Bonn, Germany
[f] Center for Quality and Applied Statistics, Rochester Institute of Technology, Rochester, NY, USA
[g] Golisano College for Computing & Information Sciences, Rochester Institute of Technology, Rochester, NY, USA
[h] Kate Gleason College of Engineering, Rochester Institute of Technology, Rochester, NY, USA
[i] Disaster Management Training and Education Centre for Africa (DiMTEC), University of the Free State, Bloemfontein, South Africa

ARTICLE INFO

Keywords:
Disaster risk management
Geographic information
GIS
Capacity
Sustainable development

ABSTRACT

The capacity to utilize geographic information is a critical element of disaster risk management. Although access to and use of geographic information system (GIS) technology continues to grow, there remain significant gaps in approaches used by disaster risk management stakeholders to understand geographic information needs, sources, and information flow—ultimately limiting the efficacy of management efforts. To address this problem, we introduce the concept of geographic information capacity (GIC) to measure and analyze the ability of stakeholders to understand, access, and work with geographic information for disaster risk management. We propose a framework for assessing GIC, the GIC Profile, which we situate within a review of disaster risk management-relevant frameworks. We evaluate the GIC Profile using two case study countries at the first (sub-national) geo-administrative boundary level. Chi-square analyses suggest GIC across equivalent regional units within each country is relatively uniform, and that this uniformity is comparable between nations despite significant difference in overall capacity. Contributions of the GIC Profile to disaster risk management research are twofold. First, this is a first attempt to develop a profile based on key indicators for quantifying GIC highlights critical areas for capacity improvement, allowing decision makers to identify and prioritize pathways to strengthen disaster risk management programs. Through this initial effort, a decision tool has been developed which may enhance decisions on how to utilize GIS in support of disaster risk management. This tool is iterative and can be updated as new events occur to maximize GIS benefits, ultimately reducing disaster risks and their potential consequences.

1. Introduction

1.1. Conceptual background

The scope, intensity, and frequency of disasters are increasing at a global scale; and with them the cost of social, economic, and environmental damages [45]. Contemporary approaches to disaster mitigation, response, recovery, and preparedness (collectively, disaster risk management) have in many cases come to rely heavily on the use of geographic information systems (GIS). Several well-established and widely accessible initiatives and mechanisms at the international scale—such as Copernicus, the International Charter Space and Major

* Corresponding author.
E-mail address: bmtski@rit.edu (B.M. Tomaszewski).
[1] These authors also contributed equally to this work.

https://doi.org/10.1016/j.ijdrr.2020.101638
Received 13 December 2019; Received in revised form 24 April 2020; Accepted 28 April 2020
Available online 4 May 2020

Disasters, Sentinel Asia, SERVIR, the Regional Service for Remote Image Processing (French: SERTIT), and the United Nations Operational Satellite Applications Programme (UNOSAT)—currently provide access to and analysis of geographic information for this purpose [15,19,41,75,87]. The application of GIS software and technology for disaster risk management (as opposed to the broader scientific field of Geographic Information Science and Technology which is not tied to a specific application domain such as disaster risk management) is also widespread in scientific literature. For instance, Cutter [18] made an early call for the use of GIS for emergency management. Tomaszewski [75] provides a comprehensive examination of GIS adaptation policy, institutional issues, datasets, and technology related to the four phases of disaster risk management. Likewise, Tomaszewski et al. provide an in-depth review [76] of the application of GIS to the disaster response phase specifically.

Despite the availability of these tools, however, disasters continue to expose inadequacies in the *capacity* of government agencies and other stakeholders to capture, communicate, and work with geographic information. In particular, insufficient availability of digital geographic information, lack of awareness about geographic information among disaster risk management actors, and computing resource limitations (i.e. hardware and GIS software) considerably impede the efficacy of disaster risk management efforts [17,76]. Ultimately, these shortcomings translate directly into untold economic damages, environmental compromise, and lost human lives. For example, with nearly 22,000 casualties and $10 billion in damages, the 2015 earthquake in Nepal demonstrated these consequences clearly. Commenting on the event, disaster risk management leaders posit that “Lack of information on affected peoples' location can jeopardise the success of post-disaster relief operations. Such information is the most critical emergency prevention tool [4] …”.

While most research in this space focuses on the development and implementation of GIS tools (e.g. datasets, software, and application integrations), research regarding geographic information capacity (GIC) specifically as an indicator for how well strategic decision makers are able to leverage geographic information and subsequent GIS tools for disaster risk management remains scarce. For example, the well-established Geographic Information Science and Technology Body of Knowledge (GIS&T BoK) does not include an entry on GIC [47]. Additionally, few studies attempt to define GIC, its impacts, or the methods of its assessment, and none do so with any robust sense of contextual adaptability. Yet, *capacity* as such is widely cited in seminal international diplomatic agreements as a critical foundation upon which the development of effective disaster risk management strategies invariably rely. The Paris Agreement under the UN Framework Convention on Climate Change, for instance, unifies member states in ambitious efforts to combat climate change and adapt to its effects, highlighting governance, technical, and data sharing capacities as essential to achieving these ends. Likewise, several other United Nations agreements—such as the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals, the New Urban Agenda, and the Convention to Combat Desertification—also call for such capacity development at the national level, and in many cases explicitly highlight geographic information capacity as a central tenet of their priorities for action (Section 1.2). Despite this recognition, however, these frameworks function in practice as high-level policy guidance documents, and thus do not provide specific direction on how such capacity might be monitored, measured, or developed. As non-exhaustive, representative examples, specific guidance on how to measure and evaluate institutional and community capacities to utilize geographic information for disaster risk reduction. Further details on how the GIC profile can work in conjunction with high-level policy frameworks are discussed in section 1.2 Thus, there remains a significant lack of broadly applicable mechanisms by which national parties may operationalize their commitments under these various agreements. To that end, we propose the GIC Profile as both a unified guideline to support the implementation of these high-level frameworks and an operational instrument for measuring, monitoring, and developing geographic information capacity for disaster risk management in pursuit of various framework goals. The GIC Profile methodology we propose identifies key practical, technological, and administrative guidelines that support the use of geographic information and GIS tools for disaster risk management, and synthesizes a means to assess their presence in a given case, providing quantitative metrics to describe categorized facets of disaster preparedness. This paper outlines the development of the GIC Profile methodology, and illustrates how the information provided via the GIC Profile might be used in both the system administration and operational deployment of disaster risk management programs.

In Section 1.2 below, we describe five of the most relevant and widely recognized United Nations policy frameworks broadly related to disaster risk management. We selected these specific policy frameworks as each framework is (a) well known and accepted by the international disaster risk management community and (b) demonstrate the need for unified and adaptable methodology for capacity development, such as the GIC Profile. Fig. 1 outlines the relationship between the five frameworks discussed in section 1.2 and the five categories of GIC we discuss in further details in section 2.1.3.

1.2. United Nations framework imperatives

1.2.1. UN Sendai Framework for disaster risk reduction (SFDRR)

Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework) is the first major agreement of the post-2015 development agenda aiming to provide a unified blueprint for policy and governance strategies that mitigate economic, environmental, and human health losses in the face of natural hazards and human-made disasters. The framework highlights four driving priorities for action [82]: 1) understanding risk, 2) strengthening governance and management approaches, 3) investing in resilience measures, and 4) enhancing response preparedness. Geographic information is specifically referenced as a critical element in achieving these ends, particularly with regard to the first priority—understanding risk [1.24f, 1.24f, & 1.25c]. The framework also extensively mentions the need for methods to assess capacities for information collection, communication, analysis, and management [2.16g; 4.24a, 4.24j, & 4.27c].

Furthermore, many of the framework's technical recommendations for risk reduction actions align squarely with—and thus depend upon measuring and developing—the five geographic information capacities we outline later in section 2.1.3. Sendai specifically cites critical needs in understanding populations [83] [1.6, 4.30f, 4.33c, & 4.33i], developing institutional expertise [2.17, 3.19a, 4.22.4.25e, 4.26e, & 5.36b], strengthening and leveraging the role of communities [3.19d, 4.24i], improving stakeholder collaboration [1.7, 3.19b, 3.19e, 4.25d, 4.31a, 4.31f, & 6.48a], and building and optimizing environmental resource knowledge [4.30f, 4.33c, 6.48b].

Even at the basic conceptual level, Sendai calls for exactly the kind of capability the GIC Profile aims to provide, highlighting the need for “means...to stimulate and contribute to developing knowledge and capacities for disaster risk reduction,” “methodologies and standards for risk assessments,” identification of “research and technology gaps...for priority areas,” and “support of the interface between policy and science for decision making” [4.22, 4.25g, 5.36b].

Although the Sendai Framework is a useful document for aligning international priorities for disaster risk reduction, it does not provide specific guidance on how these priorities might be practically implemented, measured, or ultimately achieved. Efforts that are building upon the Sendai Framework, such as the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) are working to implement Sendai priorities by making GIC a top-level priority in strategic frameworks: “Priority 2: Awareness Raising and Capacity Building Risks and impacts of disasters will be properly managed if Member States and other stakeholders are fully aware of their

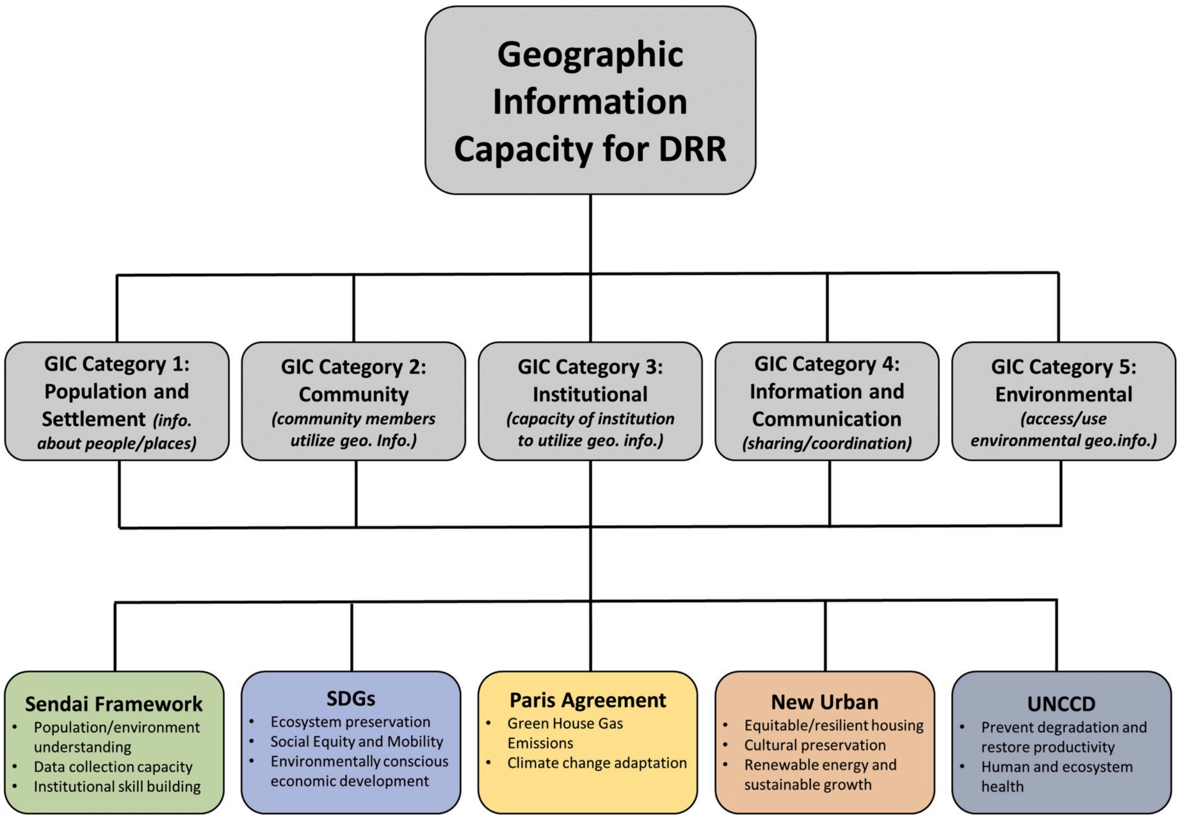

Fig. 1. International diplomatic frameworks (shown as rounded rectangles) each call for categories of GIC (as seen in the gray rounded rectangles and discussed further in section 2.1.3), both explicitly in their text, and implicitly in the nature of their underlying goals.

respective geospatial data and information holdings [81].”

In this sense, the GIC Profile can function as an instrument for operationalizing the Sendai Framework's key priorities for action, highlighting need areas, and tracking progress towards member states' commitments.

1.2.2. UN Sustainable Development Goals

Part of the United Nations 2030 Agenda, the well-known Sustainable Development Goals (SDGs) are a set of 17 goals that reflect conditions necessary for a socially, environmentally, and economically stable global society, see Ref. [20]: for the complete list of SDGs. Geographic information is most explicitly cited within the SDGs as a requisite tool for implementation (SDG 17: Partnerships for the Goals) of the SDG framework into existing national policy and technology structures. Target 18 within SDG 17 specifically cites geographic information covering population and settlement statistics, which is most applicable to SDGs 1–5 (poverty hunger, health, education, gender), 8 (work and economic growth), and 10 (reduced inequality). In addition, SDG 11 (sustainable cities and communities) specifically highlights the need for policies toward climate change adaptation, resilience, and disaster risk management in building Sustainable Cities & Communities, making direct reference to the Sendai Framework as a guideline for strategy development. In a similar vein, geographic information relating to environmental resources—an equally important data category within the GIC Profile—is also essential to achieving ecologically-focused SDGs, including 6 (water/sanitation), 8 (work and economic growth), and 12–15 (responsible consumption/production, climate action, life below water, life on land). Focusing on water, energy, climate change, and ecosystem health, these goals serve to preserve and strengthen natural environmental systems that inherently function to mitigate disaster risk by reducing the likelihood and impact of disaster events [73].

It is clear that the ability to utilize geographic information for policy development is an essential competency in enabling national-level progress on the SDGs at large and disaster risk reduction specifically in that context. Developing a consistent means by which to assess (and thereby stimulate the improvement of) the capacity to access and work with such information is a vital first step in developing such competency and achieving these goals. By providing national entities with a tool to assess their own geographic information capacity, the GIC Profile tool may thus help such states improve their understanding about the value of geographic data and information holdings, engendering progress toward more effective risk management.

1.2.3. Paris Agreement

The Paris Agreement is an international policy instrument under the UN Framework Convention on Climate Change (UNFCCC) that calls on its parties to commit to both mitigating and adapting to the effects of anthropogenic climate change through investment, technology development, information and resource sharing, and internal policy. Without major and rapid action, such climate change is widely understood to profoundly increase the frequency and intensity of extreme weather events, as well as compromise critical ecological systems that support global environmental stability [46]. In other words, climate change is itself a major driver of natural disaster risk, to such an extent that in many ways it threatens the very social and economic structures upon which global societies widely depend. In response to this threat, the Paris Agreement holds parties accountable for their contributions to such change, and serves as a primary reference point for global efforts in cooperative sustainable development.

Although the central objective is a large-scale reduction of greenhouse gas emissions (GHGs), the agreement highlights several critical competencies requisite to the achievement of its goals. These include clarity and transparency in information communication [4.8, 7.7b, 9.5, 9.7, 11.1], technical capacities for data gathering and analysis [7.7b, 11.1–3, 11.5], and involvement of the public and communities in implementing change [6.4b, 6.8b, 11.1]. Each of these themes aligns with a core capacity identified within the GIC Profile (information communication, institutional, and community capacities, respectively), suggesting, in turn, that the proposed tool may be an effective means to assess, monitor, and improve these competencies.

In addition, the Paris Agreement's underlying mission—mitigation of and adaptation to climate change—inherently necessitates understanding the location and interaction of GHG sources and sinks, as well as the location and characteristics of at-risk settlements, populations, and environmental features. In this way, geographic information (particularly with respect to populations, settlements, and environmental resources) is implicitly essential to the Paris Agreement's core mission. By extension, then, a unified mechanism by which the Agreement's parties can assess and improve their capacity to gather, communicate, and work with such information is a necessary component of a globally-consistent implementation approach.

1.2.4. New Urban Agenda

As a part of the United Nations Conference on Housing and Sustainable Urban Development (Habitat III), the New Urban Agenda (NUA) provides a blueprint for characteristics of safe, affordable, and sustainable cities. With nearly two thirds of the world's population expected to live within urban areas by 2050, the NUA seeks to establish developmental guidelines that allow for this growth to empower, rather than impoverish, such populations [53]. To that end the NUA cites six basic principles for urban development: nondiscrimination in housing access; poverty elimination; equitable standard of living (with respect to water, food, housing, and education quality); environmentally-conscious promotion of social interaction; promotion of culture through preservation; and generation and use of affordable and renewable energy.

Geographic information is, of course, an absolutely essential component of sustainable urban development. Population and settlement data, in particular, hold important information about drivers of poverty, at risk populations, barriers to socioeconomic mobility, and their resultant effects on housing, education, and social quality [Paragraphs:11, 13, 14a, 25–26, 31–34, 36–37, 39–40, 43–46, 50, 54–56, 61–62]. Recognizing this, the NUA calls for member states to develop technical competencies at the institutional level—i.e. government agencies, university research centers, and private sector stakeholders—that enable them to better understand population dynamics and thus best allocate resources towards development priorities [Paragraphs:15b, 15c.i-ii, 23, 29, 40–42, 47–48, 77, 82, 86, 104, 140, 142–144, 147–149, 157]. In the same vein, the NUA highlights the criticality of effective and transparent data sharing in order to create a compatible interface between science and policy [Paragraphs: 13g, 14c, 21, 47, 50, 87, 92, 101, 117, 123, 150, 156, 160].

Across all of these priorities, however, the NUA recognizes that the most sustainable and equitable cities are and will be those that minimize their vulnerability to, and maximize their resilience against, disasters that are likely to emerge as the global climate change trajectory continues to fall short of published recommendations. Disaster risk reduction is specifically mentioned as a key element in urban development strategy that inherently supports all of the NUA's qualitative goals [Paragraphs: 6, 13g, 19, 29, 63]. In this sense, geographic information, and the ability to analyze it, plays an even more important role in shaping development. To that end, the NUA calls for data access and analysis capabilities with respect to, *inter alia,* natural resources and environmental threats [Paragraph 65], risk distribution throughout variable built environments [Paragraph 67], and critical infrastructure for both vulnerability reduction and resilience building.

In this light, it is quite clear that the capacity to collect, analyze, and work with geographic information of all kinds is essential to achieving the goals of the NUA, and therein supporting sustainable development of global human society at large. Like each other framework mentioned above, then, the parties to the NUA stand to benefit immensely from a unified tool that enables them to assess, monitor, and improve their capabilities for geographic information management. By providing just such a tool, the GIC Profile creates a contextually adaptable platform for implementing and executing not just the mission of the NUA, but each other international commitment here outlined as well.

1.2.5. UN convention to Combat Desertification (UNCCD)

The United Nations Convention to Combat Desertification (UNCCD) 2018–2030 Strategic Framework is another global commitment under which the proposed GIC Profile can serve as a tool for practical implementation of priorities for action under the GIC Profile, but other international commitments are outlined here as well. The UNCCD Framework is a legally binding international agreement linking environment and development to sustainable land management. Its main goal is Land Degradation Neutrality, a state wherein the amount and quality of land resources supporting ecosystem functions, services, and food security remains stable or increases. This is an important, but often overlooked element of disaster risk reduction. Because desertification increases vulnerability to and the impacts of flooding, decreases food and water security, displaces populations, and compromises ecosystems, it is widely considered in the same category as natural hazards and other disasters [71].

To combat these effects, the framework establishes five strategic objectives that focus on 1) land-based ecosystem health, 2) human health in vulnerable ecosystem areas, 3) drought mitigation and resilience, 4) generating global environmental benefits, and 5) creating resource partnerships to facilitate implementation. The first four, of course, fundamentally depend upon the ability to access and analyze geographic information to support land management decisions. In particular, geographic information about environmental resources, including ecosystems, soil types, watersheds, and biological productivity are central to objectives one, three, and four. Likewise, spatial data concerning population and settlement characteristics, built infrastructure, and centers of economic productivity are imperative to both the second and third objectives.

Thus, it is clear that implementing and executing the priorities of the UNCCD Framework critically depends on each party's geographic information capacity. Although the fifth objective calls for partnerships in analysis tools, decision mechanisms, and funding, the value of such partnerships remains dependent upon the quality of data to which they have access. Further, actionable decisions are typically made at the independent national level, suggesting that each party must itself maintain some institutional competencies. In this sense, there is a clear need for a mechanism by which parties can assess their GIC and identify key areas for improvement; such a mechanism, in turn, will ensure that parties can provide high-value spatial data to inform resource allocation, technology development, and policy decisions at the national level.

1.3. Related frameworks

It is important to note too that other, important, quantitative indices have been created to evaluate specific metrics of countries to assess the need for context-specific improvement related to natural disasters and risks. The World Risk Index (WRI) and Human Development Index (HDI) have been successful in highlighting areas in need of assistance to improve the resilience and standard of living in countries through collaborations with the United Nations, governments, and non-governmental organizations (NGOs) [12]. As a result of the increasing disasters from climate change, a climate risk index (CRI), for example, was created at the country-level in Italy to help with policies and emergency response plans using equal weighting of indicators that pulls from existing knowledge [52]. The Geospatial Readiness Index assesses the geospatial preparedness of 50 countries focusing on geospatial technologies and policies available from a commercial geospatial industry perspective [27]. Additionally, the Disaster Deficit Index (DDI) was developed for the United Nations Development Programme (UNDP) to assess the economic vulnerability of a country quantified by disaster fatalities. However, this index has only been populated for the Caribbean and Latin American regions and thus cannot compare countries globally. The Value of Geoinformation for Disaster and Risk Management (VALID) report addresses the need for coping capacity throughout the disaster risk management cycle [1], underscoring the importance of proactively assessing the GIC at different spatial levels.

At the city level, in Mumbai, for example, a disaster risk index (DRI) was created using the World Risk Index (WRI) and spatial pattern analysis to rank the vulnerability of groups in the city [4]. Combining disaster risk reduction and climate change adaptation, a city resilience framework followed by a city resilience index was created to communicate ways to increase community resilience in the face of multiple hazards and compare cities rather than rank them [34]. All of the aforementioned indices provide awareness and information to support decision-making at different spatial levels. However, the goal of the GIC Profile is to identify areas of improvement to help facilitate increased GIC, identify areas for GIC improvement through internal development in a given country and/or global partnerships.

1.4. Applications of GIC

Thus, it is clear that although understudied, GIC is vital across contexts—from climate change to land use to sustainable development—to enable the deployment of beneficial GIS tools in support of global diplomatic and developmental goals as per the previously discussed frameworks and indices. To these ends, In Section 2, we propose a means by which to measure GIC using a set of 63 key indicators reflective of competencies found to be most critical to successful application of geographic information for disaster risk management activities. These indicators are derived from both insights developed through field experience in disaster risk management initiatives at the United Nations, as well as a review of critical topics discussed in disaster risk management literature [3,13,16,18,21,39,42,62,78] (Table 2). Section 3 provides a case study of applying the indicators at the sub-national level, including statistical analysis of GIC Profiles both within and between representative developed and developing nations. Section 4 provides discussion on the implications of these analyses in both the specific cases, as well as the broader context of global disaster risk management. Finally, Section 5 considers the role of this work in achieving human resilience, security, and sustainability through various global initiatives, and suggests how this work might provide a foundation for future development of GIS competencies toward that end.

2. Methodology

This section provides a background and analysis of the GIC indicator framework, as well as a methodology for developing a GIC Profile for a given context. While we use the first administrative level (FAL, i.e. sub-national regions, whether states, provinces, departments, or other [30] as a case study here, the GIC assessment framework and profile analysis concepts can be applied at any administrative scale and across any context. It is important to highlight that GIC is assessed in this manuscript for the purpose of disaster risk management. If GIC was assessed for another purpose (e.g. business opportunities), different datasets and indicators would be necessary.

2.1. GIC profile development

2.1.1. GIC definition

The United Nations Office for Disaster Risk Reduction suggests that an organization's capacity is in the aggregation of all strengths, attributes, and resources present within the community, society, or organization that can be utilized to achieve an agreed goal [83]. Similarly, the Sendai Framework for Disaster Risk Reduction makes geospatial information a key priority, highlighting the criticality of an ability to "develop, periodically update, and disseminate… location-based disaster risk information…to decision makers, the general public, and communities at risk of exposure to disaster by using geospatial information technology [83]." Combining conceptual elements from these authoritative sources, we define GIC as:

The overall ability of a community, society, government, or other organization to support disaster risk management initiatives by utilizing geographic information to make informed, evidence-based decisions and achieve agreed upon goals. This ability requires both awareness of and access to geographic information as well as the practical knowledge to use geospatial technologies effectively in its capture, analysis, and communication.

2.1.2. Technical approach

Using this definition of GIC, we define five constituent categories of geographic information capacity: 1) high-level population and settlement location data; 2) community capacity for information access and use; 3) institutional and industrial capacity for information access and use; 4) regional capacity for information flow between these sectors, communities, and institutions; and 5) environmentally-related data. These categories reflect the information types, user classifications, and relationships most critical not only to building GIC, but to societal systems analysis more broadly. Within each category, we identify key sub-categories of data (e.g. population demographics data), and then specific informational variables (e.g. data on the spatial distribution of racial groups) that together constitute a capacity to work with geographic information. In section 2.2.1, we then apply the GIC categories into practical use via a binary question-based method adapted from other disciplines [42,68,74] to assess capacities for each variable. Binary values are then aggregated into a capacity score for each GIC category, and then for GIC overall. GIC values are then analyzed using ArcGIS software to visualize the GIC Profile at the first administrative boundary. Finally, Chi-square statistical inference is used to validate the GIC Profile.

2.1.3. GIC categories

Using an indicator selection process modeled on that of the UN Development Programme [60], we derive from existing literature five categories of geographic information types and capacities we describe here as GIC Categories. These categories are suitably high-level to enable adaptability between geospatial contexts and across administrative scales. The dataset example list is also not exhaustive and could have included datasets such as roads for transportation of hazardous goods, distribution points for food and water, and many others. However, for this first attempt in estimating GIC they are sufficiently narrow in scope to ensure that the metrics of their constituent elements are specific, measurable, attainable, relevant, and trackable. The five GIC Profile categories discussed in the subsequent sections are briefly summarized in terms of their purpose in Table 1.

While these categories are designed to guide assessment of a comprehensive and specific GIC Profile, we recognize the need for adaptive flexibility. Thus, we promote a standardized framework, but acknowledge that these categories may not be immutable in application. Although this work advances a specific arrangement of GIC categories and sub-categories, that is, practical application of GIC by stakeholders may require adjustment.

2.1.3.1. Population and settlement statistics. This category assesses the capacity to produce, collect, access, and analyze statistics and other geographic information about people and the places in which they live. Many countries still struggle with the capacity to provide basic, descriptive, and useable census data, let alone higher-resolution sub-national analysis [43,61,80]. Such data is not only essential in

Table 1
Summary table of GIC Profile categories that are discussed in the subsequent sections.

Capacity Category	Example Spatial Features	Geographic Scale
Population and Settlement Statistics	The capacity to utilize and the availability of information that include but are not limited to disabled, minority, elderly, children, impoverished, and total populations, settlement quality, type, physical infrastructure, as well as any reference datasets that provide a capacity to understand population and settlement statistics	Local
Community	The availability of information to determine the percentage of population with spatial awareness, education, or past disaster experience (e.g. participatory mapping).	Local Regional
Institutional	Information availability for awareness of geo-capability, availability of GIS training/trained personnel, availability of GIS technologies (commercial and open-source), integration of GIS with relevant institutions that include but are not limited to, hospitals and emergency responders, and government management and coordination ability.	Local Regional National
Information and Communication	The availability of information to assess early warning systems, historical disaster data, map quality standards, data protection services, metadata, access to satellite imagery, effective grid infrastructure for data sharing.	Local Regional National
Environmental	Information availability for climate, topography, hydrology, land use land cover, ecosystem services, fire flow, hydrographs/flood records, and impervious surfaces.	Local Regional National

identifying the distribution and location of the most vulnerable populations, but also in managing infrastructure systems critical to population mobility and economic resilience. In a disaster event, access to this information can aid in saving lives and resources in the most direct sense.

A particular challenge in this space is that vulnerable settlements and population groups can be difficult to accurately locate precisely because their vulnerability factors make it difficult for them to self-identify or be reached by modern data collection resources. Local knowledge is therefore a critical supplement to conventional data [77]. Collecting such local knowledge can simultaneously be a pathway for community engagement, adding value to a managing entity's GIC by developing community awareness of disaster risks and associated reduction strategies [88]. Understanding the location, stability, and output of key agriculture fields or fishing ports, for example, can strengthen GIS-based disaster risk reduction both in physical planning (because these places are particularly vulnerable to destruction) and economic resilience building (as such resources are key income generators) [78].

2.1.3.2. Community. The capacity of community members themselves to utilize geographic information for ground-level disaster risk management is often undervalued and overlooked. Community GIC is manifested in several forms. Access to and utilization of local knowledge of hazard geographies and the demographic composition of communities, for example, is an essential aspect of GIC because it provides information not otherwise available in base maps, traditional earth observation tools, or census data [56]. Thus, the ability to collect spatial community information is itself an important community capacity both before and after a disaster occurs. In this context, a clear indicator for community capacity might be Public Participation GIS (PPGIS) programs in local communities that complement conventional methods of

Table 2
Binary questions used to determine GIC values.

Sub-Categories and Justification Sources	Variables	Binary Questions
1. Population and Settlement Statistics		
1.1 Demographics Sources: [16,18,24,37]	Population Density	Do you have data on population density?
	Persons with Disabilities	Do you have data on where persons with disabilities reside?
	Minorities	Do you have data on where minorities reside?
	Elderly Populations	Do you have data on where elderly persons reside?
	Children	Do you have data on where children reside?
1.2 Economics Sources: [39,78]	Economic Status	Do you have data on the economic status of residents?
	Schools	Do you have data on school locations?
	Health Insurance	Do you require your residents to have health insurance?
	Property Insurance	Do you require your residents to have property insurance?
	Tourist Attractions	Do you have data on where tourist attractions are?
1.3 Settlement Data Sources: [13,48,56,62]	Housing Type	Do you have data on the locations of different housing types?
	Housing Quality	Do you have data on locations of different quality housing?
	Road Type	Do you have data on locations of different road types?
	Traffic	Do you have data available on the current traffic situation?
	Transportation Infrastructure	Do you have data on the locations of different transportation infrastructures?
	Traffic Signals	Do you have data on the locations of traffic signal systems?
	Transportation Modes	Do you have available data on the locations of different modes of transportation?
1.4 Services Sources: [18,48,78]	Emergency Services	Do you have data on the locations of emergency services?
	Shelters	Do you have data on the locations of shelters?
2. Community Capacity		
2.1 Education Sources: [11,13,34,50]	Level of Education	Do the majority (>50%) of your residents have at least a high school equivalent education?
	GIS/Geography Programs (Primary)	Do you offer GIS/Geography Programs (Primary Level)?
	GIS/Geography Programs (Secondary)	Do you offer GIS/Geography Programs (Secondary Level)?
	GIS/Geography Programs (Tertiary)	Do you offer GIS/Geography Programs (e.g. soft GIS skills) (Tertiary Level)?
2.2 Previous Disaster Experience Sources: [3,14,17,21,35–37,76,78]	Disaster Patterns	Has your community identified a pattern in the occurrence of disasters (e.g. monsoon season)?
	Disaster Frequency	Is your country ranked in the lowest 100 countries for the "exposure" portion of the World Risk Index?
2.3 Community Leadership Sources: [20,21]	Local Groups	Do you have any local groups that practice spatial thinking (e.g. scouts, recreational geocaching, orienteering clubs)?
	Designated Observers	Do you have a designated observer/group to report any early signs of a disaster?
	Community Responders	Do you have data on individuals with disaster applicable training (i.e. military, first responders)?
3. Institutional Capacity		

(*continued on next page*)

Table 2 (*continued*)

Sub-Categories and Justification Sources	Variables	Binary Questions
3.1 Government GIS Capability Sources: [13,54,81]	Presence of GIS Department	Do you have a governmental GIS department?
	Offering GIS Training	Do you offer GIS training from the government?
	Open Access GIS Data	Do you offer open source GIS information for your region?
3.2 Commercial GIS Capability Sources: [13,81]	Presence of a GIS Centric Company	Do you have at least one company that offers GIS services as a main product?
	Offering GIS Training	Do you have a commercial GIS company that offers training?
	Data Storage Service	Do you have a commercial GIS company that offers data storage options as a service?
	Integration of GIS with Emergency Services	Do your first responders/emergency services use GIS?
3.3 Response Coordination System Sources: [11,22]	Pre-Determined Task Force	Do you have a predetermined task force trained in GIS for disaster response?
4. Information and Communication Capacity		
4.1 Disaster Warning Systems Sources: [13,42,78]	Audio/Visual Warning System	Do you have data on locations of visual and/or auditory warning system components?
	Electronic Alert System	Do you have data on the reach of electronic alert system?
4.2 Disaster Preparedness Systems Sources: [13,21,42]	Disaster Signage	Do you have disaster signage (e.g. shelter locations, instructions)?
	Disaster Drills	Do you implement disaster drills (e.g. utilize hardware for drills)?
	Emergency Preparedness Plan	Do you have an emergency preparedness checklist/plan available for citizens?
	Emergency Preparedness Classes	Do you offer emergency preparedness classes?
4.3 Information Sharing Sources: [21,24,38,56]	Timely Satellite Imagery	Do you have access to timely satellite imagery?
	Remote Telemetry	Do you have access to remote telemetry?
	Data Sharing Standard Operating Procedure	Do you have a data sharing standard operating procedure?
	Standard Data Conversion Processes	Do you have a standard data conversion process?
4.4 Data Standards Sources: [56,63]	Data Quality Standards	Do you have data quality standards?
	Map Quality Standards	Do you have map quality standards?
	Metadata Standards	Do you have metadata standards?
	Data Security	Do you have data security standards/is data stored securely?
	Record Retention Time	Do you have record retention time standards?
	Historical Disaster Data	Do you have historical data from at least the past 50 years?
	Data Backup	Do you have data backup standards/is your data backed-up?
5. Environmental Capacity		
5.1 Meteorological Data Sources: [57,73]	Climate Data	Do you have climate records/data?
	Real Time Weather Data	Do you have real time weather data?
5.2 Surface Data Sources: [13,34,62,83]	Topography	Do you have topographical data?
	Land Use Land Cover	Do you have data on land use and land cover?
	Impervious Surfaces	Do you have impervious surface data?
	Ecosystem Services	Do you have ecosystem service data?
	Fire Flow	Do you have fire flow data?
	Hydrographs/Flood Records	Do you have hydrograph/flood data?
5.3 Sub-Surface Data Sources: [13,34,59,62,83,86]	Hydrology	Do you have hydrology data?
	Geology/Soil Composition	Do you have geology/soil composition data?

information collection, organization, and use [48]. PPGIS brings end users together with professionals in a collaborative environment to help focus attention where it is needed; in this model, feedback on key focus areas is derived from the public, and policy action decisions are driven at the agency management level in response [39]. In many cases, the link between community knowledge on vulnerability and policy action on risk reduction is an external facilitator that assumes responsibility for the technical aspects of a community mapping project—another indicator of community GIC [13].

Ultimately, community capacities of all kinds not only strengthen GIC, but also create a sense of place within the community, empowering people to take more meaningful actions in disaster planning and response [55,56]. This sense of place and empowerment, in turn, enables the mobilization and management of more on-the-ground resources during disaster response and recovery phases, creating potentially significant impacts on risk reduction and resilience [62,69,70,77].

2.1.3.3. Institutional. Institutional capacity reflects the ability of institutions including local and national governments, international NGOs, university research centers, and others to utilize geographic information. Public health organizations, for example, are increasingly recognizing GIS technology literacy amongst employees as a necessity in effectively managing priorities and achieving mission objectives in disaster scenarios [50]. While such technical literacy is a GIS competency, achieving such requires the capacity to develop it—indicated by things like strategic-level support for employee training, accessibility of technology resources (e.g. commercial and open-source software) in a constrained environment, and availability of technical expertise to support literacy and new tool development.

It is important to note that because these kinds of institutions are often understood to be the primary developers and users of GIS technologies (i.e. key decision makers in disaster risk management), most contemporary GIC research focuses on this level specifically as a driver of capacity. While this focus has helped developed nations increase GIC over time, developing nations worldwide continue to struggle with GIC despite support for institutional capacity building. Obstacles in technology and resource availability, geographic complexity, and cultural diversity are often compounded by challenges rooted in the foundations of institutional structure—e.g. systemic focus on socioeconomic development, relative instability of administrative leadership, and difficulty in accessing or developing requisite technical expertise [11]. As a result, implementation of practical GIS education and training programs—in support of increasing GIC—is in many cases a more complicated endeavor for developing nations.

To this end, many of the existing GIS and GIC tools and indices engineered by institutions in developed nations are designed specifically to be useable by and for the benefit of developing nations. The International Charter Space and Major Disasters, for example, enables its members to request real-time satellite imagery of a disaster event from a unified system of collaborating national space agencies [21]. For nations without their own space agency, this program provides rapid access to decisional information about the geographic effects and development of a disaster—markedly increasing institutional GIC without necessitating local development of advanced technologies and new institutions. The GIC Profile assessment tool is intended to work in a similar fashion. As an element of larger initiatives such as the Sendai Framework or UN Spider Technical Advisory Missions (TAMs) [79], the GIC Profile can be deployed as an operational instrument that provides developing nations—in concert with colleagues from international development-oriented agencies—with an adaptable guideline for GIC assessment and improvement. By integrating this guideline into internationally-accessible tools, we can therefore minimize the resource burden of increasing GIC, and thus alleviate some part of the current barriers to effective disaster risk management in developing nations.

2.1.3.4. Information and communication. Information and communication capacity reflects the efficacy with which geographic information can be shared among the public, organizations, and institutions. The sharing and coordination of geographic information is critical and time sensitive in all phases of the disaster risk management cycle, but is made immensely more complicated when disaster events challenge conventional communication channels. Furthermore, while institutional and organizational stakeholder groups are often able to maintain communication in support of policy and response actions that target the public, the flow of information both to and from the public itself remains a significant challenge for many. This challenge is rooted in several communicative factors, including the community capacity to collect and handle geographic information, the accessibility and usability of expert institutional information by the non-expert public, and the vulnerability or absence of definite channels of information flow between these stakeholder groups [8]. Engelman et al. contend [22] that such communication barriers exacerbate disaster vulnerabilities and challenge emergency responders in ways for which they may not be adequately prepared.

Thus, it is clear that information communication is crucial to disaster risk reduction. While the Sendai Framework prioritizes developing this capacity, it is not specific about the particular technical capabilities of which it is comprised or how they might be assessed [83]. To this end, the GIC Profile tool proposes a specific set of critical variables—such as clear and compatible data sharing policies, adherence to international data format standards, and inter-institutional memorandums of understanding—that affect the capacity of a managing entity to share information, and thus the efficiency and efficacy of its management lifecycle actions.

2.1.3.5. Environmental. Environmental information capacity is a broad category focused on the ability to access, utilize, and share geographic information related to both the environmental resources of a given region and the potential environmental impacts of disaster events. Environmental impacts like watershed contamination, habitat loss, and soil erosion (amongst a myriad of others) can disrupt the functioning of ecosystems that provide considerable economic and human health value [73]. Likewise, disaster events can disrupt or destroy critical environmental resources—such as natural fisheries or agricultural fields—that are critical to societal function and development. In order to accurately assess the potential for and value of these impacts, a managing entity must hold the capacity to collect and monitor ecosystem data both prior to and after disaster events to track changes and estimate their resulting social, economic, and human health impacts. Specific capacities in this space include the technical infrastructure and knowhow to support satellite imagery analysis, manual digitization, and field observation. Further, GIC in this category focuses on the availability of and ability to collect more classical geo-environmental data including hydrographs, flood records, river morphology, topography, bathymetry, hydrological information, soil drainage, meteorological data, and land use and cover statistics [77,84]. The capacity to regularly update environmental information is critical to account for environmental changes caused by both anthropogenic activity and hazard-driven degradation [77].

Of course, the Sendai Framework highlights the importance of the environment to human resilience and socioeconomic development—recognizing the complex mixture of services it provides and hazards it creates [83]. As such, environmentally-related geographic information is critical to not only disaster risk management, but, by extension, also to sustainable development more broadly. In this sense, the specific capacities outlined in the GIC Profile assessment methodology provide a view of environmental GIC that is more relevant to the scope and scale of practical deployment, and thus fills a tactical gap in the Sendai Framework with an operational instrument not thus far available to key disaster risk management decision makers.

2.2. GIC profile

2.2.1. Assessment

These five categories serve as a composite picture of GIC in general. Using them as a foundation, we then decompose each category into sub-categories (of which there are seventeen) that more specifically describe the types of information each respective category encompasses. Each sub-category is in turn described with specific metrics (or variables, of which there are 63 across the five categories) that might be used to assess that type of information. Each variable is then associated with a binary indicator that reflects the presence or absence of the availability of or ability to collect that information (Table 2). Binary values are determined from publicly available data and are used to calculate GIC values for representative nations. In this early stage of development, it is important to clarify that if there was any data present for a specific variable, a binary value of 1 was assigned.

GIC assessment should ideally be completed by authorities such as governments to ensure complete availability, accessibility, and privacy of required data. In deployment, however, the GIC framework is intended to be equally as applicable as a direct interface for stakeholders and decision makers on the ground. It should be noted that this work is based largely on manually constructed datasets, as complete pre-compiled datasets are not presently available for this type of assessment. In this light, this work provides only a methodological baseline study. In practice, decision makers may find the results of this tool useful in both its utility function—determining practical pathways to GIC improvement—and, at a higher level, analyzing the suitability of their own organizations and potential collaborators to leverage this assessment tool toward global disaster risk reduction. These binary values are aggregated across sub-categories and, reflecting the extent of a managing entity's abilities in each area. These aggregate values are then combined across all five categories to produce an overall GIC score (Tables S1 and S2).

2.2.2. Modeling

This paper aims to both demonstrate what GIC looks like within and across developmental strata, and compare results of matching the GIC framework profile analysis and measurement to expected outcomes to achieve construct validity [72]. To achieve this, we test the model at the first administrative (i.e. sub-national) level, analyzing and comparing 16 German federal states with the 17 Nicaraguan administrative departments. We use publicly available data to employ the binary model in a yes (1) or no (0) format, accounting a capacity score according to the presence or absence of each of the 63 GIC questions.

Germany is selected due to its high level of GIS activity—including its position as a global seat of GIS research and international outreach—as well as its current policy on open government data [58,85,87]. Nicaragua is selected as a contrasting example according to its high rank (14th) on the World Risk Index (WRI), as well as geopolitical factors that are known to contribute to less development in their GIS capabilities [49,50]. Nicaragua's WRI rankings in vulnerability, susceptibility, and lack of coping and adaptive capacities, for example, are comparable to those of the highest ranked (i.e. least-developed) countries. This risk level is balanced, however, with an unusual availability of open source geographic data that is not as comprehensively available amongst peer LDCs [5]. This balance, considered in addition to recent destruction from Hurricane Mitch [29], and both contemporary and historical political struggles, well position Nicaragua as a representative nation to contrast Germany [28,51,65].

After collecting binary answers for each variable, values are summed with equal weighting to estimate a GIC Profile value for each FAL unit. The values are mapped by FAL unit using ESRI ArcGIS Pro so that results for each FAL can be visualized, both on the basis of individual categories and as a composite, country-level assessment of gross GIC.

2.2.3. Data analysis

To compare the individual GIC categories within a country's profile and the profiles of the case study countries, statistical analyses were performed using JMP 13 Pro Statistical software. Binary response values were compared for each FAL unit within Germany and Nicaragua, for each GIC category within each country, and between both countries using a Chi-square test of independence. For category tests, category-level GIC scores for each FAL unit were compared. For FAL comparisons, we calculate an aggregate GIC value across all five categories for each state. Finally, country-level comparisons used aggregated category values for a gross GIC score in each nation. When significant effects were found, post hoc analysis was conducted using Chi-squared pair-wise comparisons. Results were considered significant at $p < 0.05$.

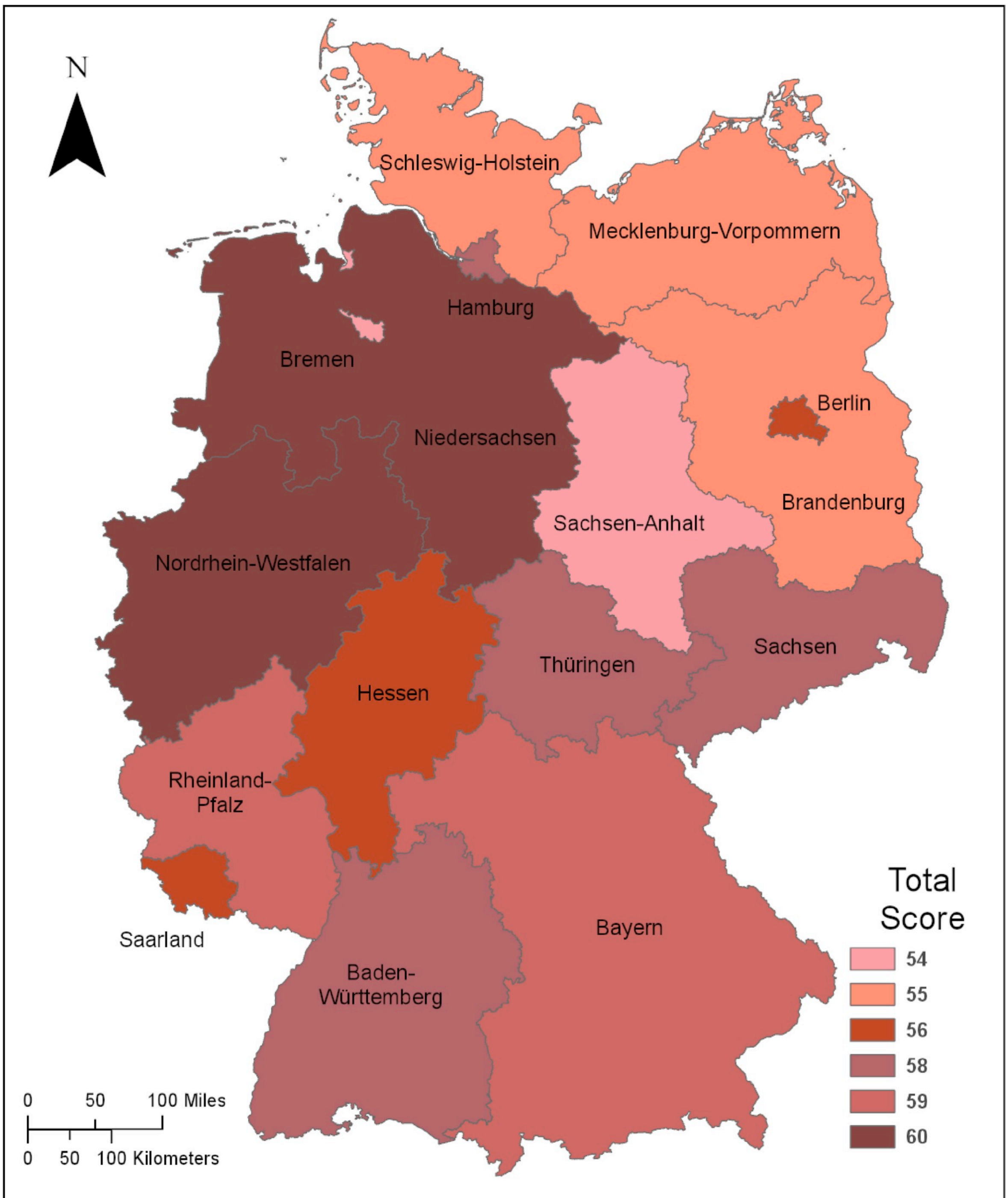

Fig. 3. Germany's total GIC Profile values by state. Total score values are out of 63 possible points.

3. Results

In the following section, we present a series of choropleth maps that graphically demonstrate the GIC Profile respectively for Germany (Fig. 3) and Nicaragua (Fig. 4) and then a normalized comparison between of the GIC Profile between the two countries (Fig. 5).

3.1. Developed Nation—Germany

.

3.2. Developing Nation—Nicaragua

.

3.3. Comparison

Full results of GIC Profile scores for Germany and Nicaragua, respectively, can be found in S1–S2 Tables.

3.4. Chi square analysis

Chi-square comparisons between (a) first administrative level within Germany and Nicaragua, (b) category comparisons within Germany and Nicaragua, and (c) overall country comparisons (Table 3).

4. Discussion

4.1. Modeling strategy

At the strategic level, the GIC Profile was developed such that it could be completed either by stakeholders with firsthand access to such information or from a third-party evaluative perspective reliant on open access to data resources. In this work, we use open data for Germany and Nicaragua to assess the GIC Profile of each country and compare them as representatives of developed and developing nations, respectively.

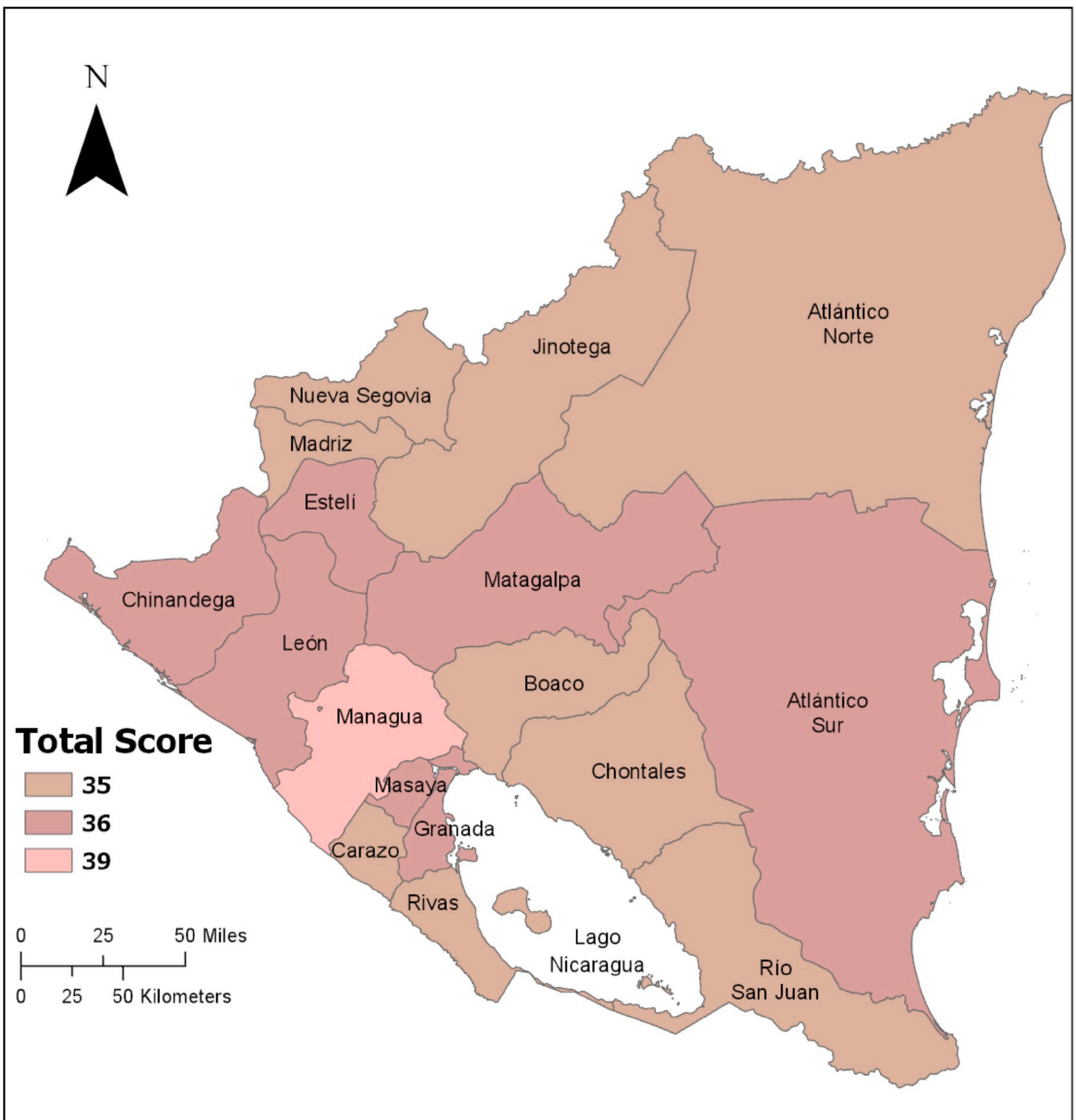

Fig. 4. Nicaragua's total GIC Profile values by state. Total score values are out of 63 possible points.

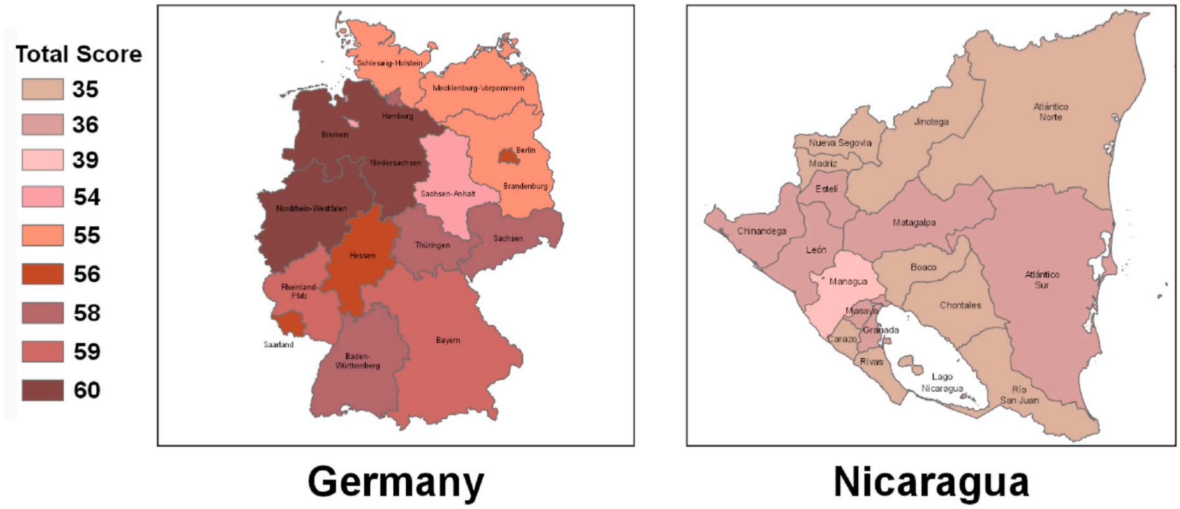

Fig. 5. Comparison of Nicaragua (left) and Germany (right) GIC Profiles on a normalized scale; 63 possible points.

Table 3
Results of Chi-squared analysis for comparing the GIC within first administrative levels, between countries, and between categories. Results were considered significant at $p < 0.05$.

Main Effect	df	X [2]	p
First administrative level Comparison: Germany	15	11.9	0.69
First administrative level Comparison: Nicaragua	16	1.03	1.00
Category Comparison: Germany	4	81.5	<0.001*
Category Comparison: Nicaragua	4	284	<0.001*
Country Comparison	1	322	<0.001*

*$p < 0.05$.

There are, of course, inherent limits to this approach when viewed at the variable level. The binary assessment of whether a given FAL unit "offer[s] postsecondary degree programs in GIS/Geography at the BS/MS/PHD level" cannot, for example, differentiate between a unit that has one such program and a unit that has many. These limits are balanced, however, by assessments that do indeed provide equitable state-level comparisons even in binary form. The capacity to collect population density data, for example, is effectively equivalent across those that have it, regardless of differences in the actual data values.

There are also some points of consideration at the operational level. The disaster risk management system in Germany, for example, prioritizes response from small entities first, then proceeds to larger entities if necessary [33]. Town resources are first utilized to respond to a hazard, and then the municipality (e.g. district or county) may assist if the hazard spreads across multiple towns. State-level resources may be requested to assist if multiple municipalities are affected and need coordination. Finally, the federal government may be requested to assist if multiple states are affected. Because hazards are not constrained by political boundaries, this stratification of response systems suggests that disaster preparedness and management capacity may be variable across regional geographies in early stages, leading to spatially differentiated risk characteristics within a single FAL. Flooding of the Rhine River in western Germany, for example, typically spans multiple federal states, meaning initial responses will come from many managing entities with differing levels of GIC before state- and federal-level authorities mobilize. In a system like this, the GIC Profile can highlight these differences in advance of disaster events, enabling strategic improvement at all levels. Local and state stakeholders, of course, can use the GIC Profile to understand where initial capacities are weak, and thereby target key areas for development. At the federal level, comparing GIC Profiles across FAL units can inform resource allocation strategy by revealing where response will be most challenged. Likewise, such comparisons can form the basis for federal capacity-building guidelines that can be adopted by individual state and local stakeholders to ensure their capacities meet the needs of a nationally-coordinated system.

4.2. Capacity drivers

In Germany (Fig. 3), the light-dark gradient represents the progression from a lower to higher GIC. Interestingly, lighter areas tend to be focused in the northeastern region, formerly the German Democratic Republic (i.e. East Germany) during the nation's Cold War era division. This disparity, though slight, may reflect politically-related delays in technology and capacity productivity in Eastern Germany whose effects remain today [6]. Supporting this notion, the Berlin region appears darker than its surrounding area, suggesting influence from the city's concentrated Western occupation throughout the Cold War.

A similar trend reflecting the relationship between policy, technology, and capacity is seen in Nicaragua's GIC Profile map (Fig. 4). Managua, for example, is Nicaragua's political and economic epicenter, its largest city, and its best-prepared department in terms of GIC. We can infer from this map that capacity development is perhaps a product of the concentration of population, resources, and political influence, and that in this sense, institutional and community capacities are particularly strong drivers of GIC overall. Comparing both German and Nicaraguan GIC Profile maps to similar visualizations of population density in each nation supports the notion that such a correlation may exist [23, 87]. In turn, this suggests that lower GIC areas—and thus, the entire nation by extension— may benefit significantly from the establishment of regional branches of government agencies or research institutions, as well as investment in public education, outreach, and knowledge development.

4.3. Uniformity trends

4.3.1. Intra-national

Statistical analysis indicates that FAL Profile values within respective countries do not significantly differ from one another. In larger disaster scenarios, where response is coordinated at the state or national level, such uniformity helps facilitate effective response. Significant differences in GIC between FAL units within a country, that is, can challenge national-level disaster risk management strategy by creating knowledge gaps during coordination decision processes. Ultimately, this impedes response and complicates resource optimization significantly. It is often the case, however, that even where national-level disaster risk management coordination frameworks do exist, regional governments within FAL units determine their own disaster risk management priorities and strategies—including the development and use of GIC. While FAL assessments can be used by these units to improve GIC internally, it seems reasonable to suggest that national stakeholders should invest in GIC development equitably across each FAL unit to ensure uniformity that facilitates national coordination.

4.3.2. International

Categorical statistical inference indicates statistically significant differences ($p < 0.05$) between GIC Profile categories for both Germany and Nicaragua. As a developed nation, one might expect that Germany would have a higher GIC in every category. While Germany's community capacity was consistently high—likely due to strong public education, well-documented disaster patterns, and cultural community structure—not all capacity categories were as strong. In particular, institutional capacity scores are relatively low and inconsistent; across its states, German institutional capacity scores range from just 25%–100%. Information specifically outlining GIS training for either state governments or capable and relevant private sector companies could not be found for many states. Likewise, state-level information on the existence of a predetermined disaster response task was not always available.

By contrast, Nicaraguan GIC values are lower across all categories. Uniformity (i.e. no statistically significant differences) across categories is due largely to the grouped nature of available databases—information on specific GIC questions is found for either all departments or none. An exception to this trend is found in community capacity; because communities are disparately and, in many cases, independently organized, the availability of information concerning how communities use spatial data is variable, found for only nine of 17 departments. Overall, analysis of Nicaraguan databases suggests that categories wherein capacity is related to top-down technology and information were stronger in general. Contexts in which either national or departmental governments are the primary determinants of access to GIS tools and related information for disaster response showed generally higher GIC. However, information about GIS program organization, educational quality, and community outreach initiatives were not positively identified, suggesting a lack of widespread GIS training and use within the general population, and thus a related gap in disaster preparedness.

4.4. Sensitivity analysis

Due to continuously changing policies, risks, and climates, the proposed GIC Profile tool is sensitive to changes. As such, to demonstrate the sensitivity of the model as well as the model's adaptability, a scenario analysis under conditions in which GIC values change are performed for both case studies. Because actual disaster events rely on proven tools, theoretical scenarios are often used in this way to test and evaluate the utility of disaster risk management technology and concepts like the proposed GIC Profile [66,67]. To assess the changes, theoretical scenarios were tested by answering the questionnaire again, under new conditions, to determine a new GIC Profile score.

First, the effect of a power outage on the GIC Profile of Germany was evaluated based on past events and research related to power outages [9, 10,31]. In this scenario, a catastrophic 72-h power outage was assumed in North Rhine-Westphalia, where electricity is therefore not available in major urban centers including Cologne, Dusseldorf, and the Ruhr Valley region. Even after 48 h, it is likely that most generators and batteries would be out of power [32], and consequently information found online or in any type of electric format would not be available and therefore the questionnaire values were assumed to now be 0. The GIC Profile is able to adjust to these changes where there would be a 40% decrease (from 95% to 57%) in the GIC Profile for North Rhine-Westphalia, which could create potential disaster risks comparable to historical power outage events [2,64] where accidental deaths increased by 122% (Table S3).

To evaluate potential GIC Profile changes in Nicaragua, we also tested another scenario in which there is a significant education reform, based on existing national education plans [5]. In this scenario, we assume that there will be future educational reform investments in the Leon Department, which has a lower GIC value than Managua under existing conditions (Fig. 4). It is assumed that the national curriculum now includes mandatory geography courses and increases in educational technology funding. As a result of this education reform, there could be new university GIS courses and degree programs, which could also increase the number of GIS experts. With an increase in the GIS workforce, GIS could be integrated into national disaster risk management agencies such as the Sistema Nacional para la Prevención*, Mitigación y Atención de Desastres' (SIN-APRED)*. These ripple effects could increase Leon's GIC Profile by 47%, raising their score from a 36 to 53 from a result of 1 to the education-based questions.

While these examples are included to illustrate the extreme impacts that catastrophic events or large-scale policy reforms could have on a region or country's GIC Profile, the key point here is that a region's GIC Profile is a dynamic model that is sensitive to changes while also being easy and quick to update. This model sensitivity and adaptability allows the GIC Profile to be continuously improved through the identification and targeting of areas with significant improvement potential. For example, while electronic records were vulnerable in the German catastrophic scenario (Table S3), community capacity and human resources were mostly unaffected and could potentially fill gaps in other areas. In the Leon education scenario, we see cascading effects where primary education led to secondary and tertiary programs being generated, which in turn could lead to a GIS educated workforce and the creation of a commercial sector.

5. Conclusions & future work

5.1. Practical implementation

German and Nicaraguan GIC Profiles significantly differ (Table 3), which was qualitatively expected by nature of the nations' respective development statuses, we assert that the model used to quantify these differences is both valid and, in turn, valuable to practical implementation of international development goals[89]. Further, the magnitude of difference between the two nations' Profiles clearly illustrates the need for capacity building in developing nations especially. We posit, then, that international parties can use the GIC Profile as a means to assess and identify key priorities for collaboration in technology, education, policy, and public outreach across developmental strata.

Using the developmentally-representative nations from this paper as an example, Germany might leverage its strong Community GIC to distill the policy instruments and education pathways that make it possible, and share those insights with the Nicaraguan federal government. The latter may in turn be empowered to promote development of community-level GIS literacy as a national strategy, reducing inequities in and barriers to information access across FAL units. Improved community capacity, of course, directly increases the public's ability to respond to and recover from disasters, not only improving resilience, but saving human lives.

Assessing and comparing Profiles of collaborating countries in this way allows targeted investment in contextually variable GIC need areas, and reduces the overall resource burden of capacity development by leveraging successful strategies where they already exist. Collaboration as such is indeed explicitly prescribed in virtually every international diplomatic agreement outlined in Section 1.2. Therefore, if the parties to these seminal agreements intend to uphold their respective commitments, deployment of practical and contextually-adaptable tools like the GIC Profile is effectively requisite. While in most cases, of course, there are no legally-binding consequences for absconding these commitments, the economic, environmental, and human social repercussions of inaction are severe, and in many cases all but terminal.

5.2. Model development

To support such collaboration, we contend that GIC Profile methodology can be deployed as an operational instrument under any of the frameworks mentioned above. The current model can be replicated through completing the questionnaire found in Table 2 through the use of the listed data resources to estimate a GIC Profile score by identifying if the data are available at the first administrative level. The model is designed to allow flexibility in application, and can be modified by users to serve as a basis for assessment specific to a given initiative's goals, if not for complete profile analysis. For example, the profile is built to be an iterative tool, where depending on different scenarios and events, the profile can be updated to include new variables that are relevant to disaster risk reduction such as assessment of the level of information technology security to fully assess potential vulnerabilities.

However, because the above-referenced frameworks so often explicitly call for geographic information and capacity building tools, we suggest that this work may best serve as a unified method for assessment and improvement. In that pursuit, continuing work should aim to develop a global, interactive user interface that is available to national stakeholders and public parties alike. We envision, for example, a web-based application or simple plugin based on open software (e.g. Google Earth or OpenStreetMap) that allows users to report and visualize their own GIC, but also to compare with international collaborators to identify growth opportunities.

Towards this goal, future work might also consider applying a weighting scheme for GIC variables that accounts for relative criticality and resource availability. The current model uses equal weighting across all variables, and thus implicitly assumes each is equally important to disaster risk reduction. However, disciplinary experts with experience in field operations, developmental economics, environmental resilience, and even sociological dynamics may be able to offer insights into how the importance of different GIC variables relates to a given country's other developmental strengths and needs [40,44]. To that end, we recommend that this debate be included in the tasks assigned to the United Nations Working Group on Geospatial Information and Services for disaster risk management [81]. Further, another future consideration could be to update the binary assessment to a Likert scale to further explore the sensitivity in the variables and add granularity to the assessment [7].

Finally, we recognize that GIC assessment is relatively independent from a nation's or FAL unit's particular disaster risk profile, and thus offers only part of a complete risk reduction solution. Disaster risk, in other words, is the product of a location's vulnerability, the likelihood of occurrence in that location, and the magnitude of impact a disaster would have given those vulnerability and likelihood conditions. While the GIC Profile may well serve to reduce vulnerability by facilitating capacity development, effective disaster risk management must account for these other factors. Consequently, we recommend that future work using the GIC Profile methodology seek to pair it with spatial risk analysis to better understand how risk interacts with capacity; i.e. whether areas with the highest risk exhibit a higher GIC, and if not, how GIC might be developed to address those risks in particular.

5.3. Global imperative

At its core, this study suggests and evaluates a novel means for national stakeholders to quantitatively evaluate GIC and identify key needs for capacity growth in order to strengthen disaster risk management systems. The eventual result of this growth, however, is the potential to reduce losses in economic, environmental, and human social health, and indeed mitigate disaster drivers from the beginning—aligning this methodology well with the underlying missions of several international diplomatic agreements to which most of the world is beholden. Model testing both reveals gap areas in case countries and confirms that developing nations are at comparatively elevated risk due to low capacity for disaster risk management through GIS. Statistical comparison between case country profiles reveals trends that fall neatly along empirical qualitative lines, thus validating the model as one that may provide valuable insights to inform national-level decisions in policy, technology, education, and public administration.

We assert, therefore, that the GIC Profile methodology fills a gap at the nexus of science, technology, and policy that has long perpetuated obstacles to data-driven and sustainable development on a global scale. This tool makes clear how information, education, and communication policy affect technical competencies, community resilience, and indeed the impacts of disasters overall by extension. Using this methodology as a means to operationalize commitments under global structures like the Sendai Framework, Paris Agreement, and Sustainable Development Goals, decision makers may be empowered to take definitive and necessary action that accounts for critical needs and resource limitations, but also leverages the potential of international collaboration.

Ultimately, as climate change and human behavior continue to exacerbate the effects of natural disasters, the need for spatially-informed disaster risk management measures increases concurrently. While geographic information and spatial tools have historically been used in disaster prediction, trajectory mapping, and effects localization, contemporary technologies are beginning to enable real-time optimization of response and recovery efforts. Now, as these technologies continue to evolve, many of those most vulnerable to the effects of disasters are left behind due to gaps in their capacity to collect, analyze, and communicate the spatial data upon which these tools rely. By providing a roadmap for GIC assessment, this methodology serves as a basis for optimizing decisions about interventions, policies, and resource investments that aim to better prepare national stakeholders—and especially developing countries—not only to respond and recover, but also to markedly improve capabilities in mitigation and planning. In so doing, GIC Profile can provide a starting point for nations to reduce vulnerability *and* proactively mitigate the likelihood and impacts of disasters as well—ultimately reducing disaster risk overall.

Acknowledgements

The authors acknowledge Rochester Institute of Technology, United Nations University Institute for Environment and Human Security, and University of Bonn for providing this unique international research opportunity. This research was funded through a grant from the US National Science Foundation and the project International Research Experience for Students: Quantifying Disaster Risk Reduction Geographic Information Capacity with United Nations University Institute for Environment and Human Security and University of Bonn Germany (NSF OISE-1559450).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2020.101638.

Declaration of interests

☐ 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.

References

[1] O. Altan, R. Backhaus, P. Boccardo, F.G. Tonolo, J. Trinder, N. Van Manen, S. Zlatanova, The Value of Geoinformation for Disaster and Risk Management (VALID): Benefit Analysis and Stakeholder Assessment. *Joint Board of Geospatial Information Societies*, 2013.

[2] G.B. Anderson, M.L. Bell, Lights out: impact of the August 2003 power outage on mortality in New York, NY, Epidemiology 23 (2) (2012) 189.

[3] S. Ayeb-Karlsson, NepalEarthquake: Preparing and Planning for the Next Disaster, 2015. Retrieved from, http://ehs.unu.edu/blog/articles/nepal-earthquake-preparing-and-planning-for-the-next-disaster.html.

[4] P. Bagewadi, D. Mukherji, Calculating Disaster Risk Index (DRI) for Greater Mumbai by Hazard Risk and Vulnerability Analysis (HRVA) Using GIS, 2017.

[5] The World Bank, DisasterRisk Management in Guatemala, 2013. Retrieved from, http://www.worldbank.org/en/results/2013/10/08/promoting-proactive-disaster-risk-management-in-Guatemala.

[6] R. Barrell, D.W. Te Velde, Catching-up of east German labour productivity in the 1990s, Ger. Econ. Rev. 1 (3) (2000) 271–297.

[7] A. Barua, Methods for decision-making in survey questionnaires based on Likert scale, J. Asian Sci. Res. 3 (1) (2013) 35–38.

[8] N. Bharosa, J. Lee, M. Janssen, Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: propositions from field exercises, Inf. Syst. Front 12 (1) (2010) 49–65.

[9] Blackout —Could it Happen in Germany?, 2003. DW. Retrieved from, https://www.dw.com/en/blackout-could-it-happen-in-germany/a-981943.

[10] Briefblackout Affects 10 Million across Europe - Europe - International Herald Tribune, 2006. New York Times. Retrieved from, https://www.nytimes.com/2006/11/05/world/europe/05iht-lights.3401291.html.

[11] J. Britton, GIS capacity building in the Pacific Island countries: facing the realities of technology, resources, geography and cultural difference, Cartographica: Int. J. Geogr. Inform. Geovisual. 37 (4) (2000) 7–19.

[12] V. Bérenger, A. Verdier-Chouchane, Multidimensional measures of well-being: standard of living and quality of life across countries, World Dev. 35 (7) (2007) 1259–1276.

[13] L. Canevari-Luzardo, J. Bastide, I. Choutet, D. Liverman, Using partial participatory GIS in vulnerability and disaster risk reduction in Grenada, Clim. Dev. 9 (2) (2017) 95–109.

[14] L.-C. Chen, Y.-C. Liu, K.-C. Chan, Integrated community-based disaster management program in Taiwan: a case study of Shang-An village, Nat. Hazards 37 (1–2) (2006) 209.

[15] Y.H. Chou, Management of wildfires with a geographical information system, Int. J. Geogr. Inf. Syst. 6 (2) (1992) 123–140.

[16] D.P. Coppola, Introduction to International Disaster Management, Elsevier, 2006.

[17] N.R. Council, M.S. Committee, Successful Response Starts with a Map: Improving Geospatial Support for Disaster Management, National Academies Press, 2007.

[18] S.L. Cutter, GI science, disasters, and emergency management, Trans. GIS 7 (4) (2003) 439–446.

[19] J.P. De Albuquerque, B. Herfort, A. Brenning, A. Zipf, A geographic approach for combining social media and authoritative data towards identifying useful information for disaster management, Int. J. Geogr. Inf. Sci. 29 (4) (2015) 667–689.

[20] U. Desa, Transforming Our World: the 2030 Agenda for Sustainable Development, 2016.

[21] Disasters, T. I. C. S. a. M, About theCharter - International Disasters Charter, 2019. Retrieved from, https://disasterscharter.org/web/guest/about-the-charter.

[22] A. Engelman, S.L. Ivey, W. Tseng, D. Dahrouge, J. Brune, L. Neuhauser, Responding to the deaf in disasters: establishing the need for systematic training for state-level emergency management agencies and community organizations, BMC Health Serv. Res. 13 (1) (2013) 84.

[23] ESRI, Population Density in Germany, 2018. Retrieved from, https://www.arcgis.com/home/item.html?id=5554e79e5c024e889e02cf4d525bd1b6.

[24] L. Fast, A. Waugaman, Fighting Ebola with Information: Learning from Data and Information Flows in the West Africa Ebola Response, USAID Report, Washington, DC, 2016. https://www.usaid.gov/sites/default/files/documents/15396/FightingEbolaWithInformation.pdf. (Accessed 10 July 2017).

[27] Geobuiz, Geospatial Industry Outlook and Readiness Index, 2018. Retrieved from, https://geobuiz.com/geobuiz-2018-report.html.

[28] H.A. Ghobarah, P. Huth, B. Russett, Civil wars kill and maim people—long after the shooting stops, Am. Polit. Sci. Rev. 97 (2) (2003) 189–202.

[29] M. Glantz, D. Jamieson, Societal response to Hurricane Mitch and intra-versus intergenerational equity issues: whose norms should apply? Risk Anal. 20 (6) (2000) 869–882.

[30] U.G.I.W. Group, Second administrative level boundaries, 2012.

[31] C. Growitsch, R. Malischek, S. Nick, H. Wetzel, The Costs of Power Interruptions in Germany-an Assessment in the Light of the Energiewende, 2013 (Retrieved from).

[32] R. Hamilton, Lessons in Emergency Power Preparedness: Planning in the Wake of Katrina, Cummins Power Generation Inc, 2007.

[33] N. Hecker, B.D. Domres, The German emergency and disaster medicine and management system—history and present, Chin. J. Traumatol. 21 (2) (2018) 64–72.

[34] C.R. Index, City Resilience Framework, The Rockefeller Foundation and ARUP, 2014.

[35] M. Ishiwatari, Chapter 2 government roles in community-based disaster risk reduction, in: Community-based Disaster Risk Reduction, Emerald Group Publishing Limited, 2012, pp. 19–33.

[36] M.N. Islam, M.A. Malak, M.N. Islam, Community-based disaster risk and vulnerability models of a coastal municipality in Bangladesh, Nat. Hazards 69 (3) (2013) 2083–2103.

[37] T. Izumi, R. Shaw, Chapter 3 role of NGOs in community-based disaster risk reduction, in: Community-based Disaster Risk Reduction, Emerald Group Publishing Limited, 2012, pp. 35–54.

[38] A. Kawasaki, M.L. Berman, W. Guan, The growing role of web-based geospatial technology in disaster response and support, Disasters 37 (2) (2013) 201–221.

[39] R.B. Kemp, Public participatory GIS in community-based disaster risk reduction. *tripleC: communication, Capitalism & Critique*, Open Access J. Glob. Sustain. Inform. Soc. 6 (2) (2008) 88–104.

[40] S. Kienberger, M. Hagenlocher, Spatial-explicit modeling of social vulnerability to malaria in East Africa, Int. J. Health Geogr. 13 (1) (2014) 29.

[41] M. Konečný, W. Reinhardt, Early Warning and Disaster Management: the Importance of Geographic Information (Part A), Taylor & Francis, 2010.

[42] H. Kruizenga, J. Seidell, H.C. de Vet, N. Wierdsma, Development and validation of a hospital screening tool for malnutrition: the short nutritional assessment questionnaire (SNAQ©), Clin. Nutr. 24 (1) (2005) 75–82.

[43] T. Kuemmerle, K. Erb, P. Meyfroidt, D. Müller, P.H. Verburg, S. Estel, T. Kastner, Challenges and opportunities in mapping land use intensity globally, Curr. Opin. Environ. Sustain. 5 (5) (2013) 484–493.

[44] D. Maguire, M. Goodchild, M. Batty, GIS, Spatial Analysis, and Modeling, Esri Press, 2005.

[45] S. Mal, R.B. Singh, C. Huggel, Climate Change, Extreme Events and Disaster Risk Reduction: towards Sustainable Development Goals, Springer, 2017.

[46] T. Masson-Delmotte, P. Zhai, H. Pörtner, D. Roberts, J. Skea, P. Shukla, R. Pidcock, IPCC, 2018: summary for policymakers, in: Global Warming of 1.5 C. An IPCC Special Report on the Impacts of Global Warming of 1.5 C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, the context of strengthening the global, Geneva, Switzerland, 2018.

[47] A. Mathews, A. Frazier, Geographic Information Science & Technology Body of Knowledge, 2017 (2nd Quarter 2017 Edition). Retried from, https://www.gistbok.ucgis.org.

[48] M. McCall, Participatory Mapping and Participatory GIS (PGIS) for CRA, Community DRR and Hazard Assessment. *ProVention Consortium, CRA Toolkit*, Participation Resources, Geneva, 2008.

[49] B.E. Mennecke, L.A. West Jr., Geographic Information Systems in developing countries: issues in data collection, implementation and management, J. Global Inf. Manag. 9 (4) (2001) 44–54.

[50] M.L. Miranda, M. Casper, J. Tootoo, L. Schieb, Peer reviewed: putting chronic disease on the map: building GIS capacity in state and local health departments, Prev. Chronic Dis. 10 (2013).

[51] J. Murdoch, T. Sandler, Civil wars and economic growth: a regional comparison, Defence Peace Econ. 13 (6) (2002) 451–464.

[52] J. Mysiak, S. Torresan, F. Bosello, M. Mistry, M. Amadio, S. Marzi, A. Sperotto, Climate risk index for Italy, Phil. Trans. Math. Phys. Eng. Sci. 376 (2121) (2018) 20170305.

[53] U. Nations, 2018 revision of world urbanization prospects, in: United Nations Department of Economic and Social Affairs, 2018.

[54] I. Pal, T. Ghosh, C. Ghosh, Institutional framework and administrative systems for effective disaster risk governance–perspectives of 2013 Cyclone Phailin in India, Int. J. Disast. Risk Reduct. 21 (2017) 350–359.

[55] B. Pandey, K. Okazaki, Community-based disaster management: empowering communities to cope with disaster risks, Reg. Dev. Dialog. 26 (2) (2005) 52.

[56] G. Peters-Guarin, M.K. McCall, C. van Westen, Coping strategies and risk manageability: using participatory geographical information systems to represent local knowledge, Disasters 36 (1) (2012) 1–27.

[57] I.M. Picketts, A.T. Werner, T.Q. Murdock, J. Curry, S.J. Déry, D. Dyer, Planning for climate change adaptation: lessons learned from a community-based workshop, Environ. Sci. Pol. 17 (2012) 82–93.

[58] E.D. Portal, Germany Brings Open Data into Law, 2018. Retrieved from, https://www.europeandataportal.eu/en/news/germany-brings-open-data-law.

[59] K. Poser, D. Dransch, Volunteered geographic information for disaster management with application to rapid flood damage estimation, Geomatica 64 (1) (2010) 89–98.

[60] U.N.D. Programme, Beyond Scarcity: Power, Poverty and the Global Water Crisis, Palgrave Macmillan, 2006.

[61] M.M. Project, Missing Maps, 2019. Retrieved from, https://www.missingmaps.org/.

[62] A. Rahman, A. Sakurai, K. Munadi, Indigenous knowledge management to enhance community resilience to tsunami risk: lessons learned from Smong traditions in Simeulue island, Indonesia, in: Paper Presented at the IOP Conference Series: Earth and Environmental Science, 2017.

[63] M. Rans, Dataset Quality Assurance Procedures, 2018. Retrieved from, https://humanitarian.atlassian.net/wiki/spaces/HDX/pages/30212102/Dataset+Quality+Assurance+Procedure.

[64] S.M. Rinaldi, J.P. Peerenboom, T.K. Kelly, Identifying, understanding, and analyzing critical infrastructure interdependencies, IEEE Contr. Syst. Mag. 21 (6) (2001) 11–25.

[65] F. Robles, Just a Week, 'Nicaragua Changed' as Protesters Cracked a Leader's Grip, NY Times, 2018. Retrieved from, https://www.nytimes.com/2018/04/26/world/americas/nicaragua-uprising-protesters.html.

[66] A. Sagun, D. Bouchlaghem, C.J. Anumba, A scenario-based study on information flow and collaboration patterns in disaster management, Disasters 33 (2) (2009) 214–238.

[67] U.D.o.H. Security, National planning scenarios, in: National Incident Management System, 2006.

[68] Y. Shang, F. Tsung, C. Zou, Profile monitoring with binary data and random predictors, J. Qual. Technol. 43 (3) (2011) 196–208.

[69] R. Shaw, Chapter 1 overview of community-based disaster risk reduction. Community-based Disaster Risk Reduction, Emerald Group Publishing Limited, 2012, pp. 3–17.

[70] R. Shaw, Y. Takeuchi, R. Krishnamurthy, J. Jacqueline Pereira, F. Mallick, Chapter 4 universities and community-based disaster risk reduction, in: Community-Based Disaster Risk Reduction, Emerald Group Publishing Limited, 2012, pp. 55–66.
[71] A. Steiner, Sudan: post-conflict environmental assessment, in: UN Environment Program, 2007.
[72] M.E. Strauss, G.T. Smith, Construct validity: advances in theory and methodology, Annu. Rev. Clin. Psychol. 5 (2009) 1–25.
[73] Z. Sutherby, B.M. Tomaszewski, Conceptualizing the Role Geographic Information Capacity Has on Quantifying Ecosystem Services under the Framework of Ecological Disaster Risk Reduction (EcoDRR). Paper Presented at the ISCRAM, 2018.
[74] J. Tiao, R. Feng, E. Berger, J. Brandsema, C. Coughlin, N. Khan, P. McMahon, Evaluation of the reliability of the cutaneous dermatomyositis disease area and severity index and the cutaneous assessment tool–binary method in juvenile dermatomyositis among paediatric dermatologists, rheumatologists and neurologists, Br. J. Dermatol. 177 (4) (2017) 1086–1092.
[75] B. Tomaszewski, Geographic Information Systems (GIS) for Disaster Management, Routledge, 2014.
[76] B. Tomaszewski, M. Judex, J. Szarzynski, C. Radestock, L. Wirkus, Geographic information systems for disaster response: a review, J. Homel. Secur. Emerg. Manag. 12 (3) (2015) 571–602.
[77] P. Tran, R. Shaw, G. Chantry, J. Norton, GIS and local knowledge in disaster management: a case study of flood risk mapping in Viet Nam, Disasters 33 (1) (2009) 152–169.
[78] H. Turral, J. Burke, J. Faurès, Climate Change, Water and Food Security, Food and Agriculture Organization of the United Nations Rome, Italy, 2011.
[79] UN-Spider, Technical Advisory Missions, 2019. Retrieved from, http://un-spider.org/advisory-support/advisory-missions/technical-advisory-missions.
[80] W. UNFPA, C. Flowminder, Geo-referenced infrastructure and demographic data for development (GRID3), 2019.
[81] United, & (UNISDR), N. O. f. D. R. R., Terminology - Capacity, 2017. Retrieved from, https://www.unisdr.org/we/inform/terminology#letter-c.
[82] United, & Reduction, N. I. S. f. D, SendaiFramework for Disaster Risk Reduction 2015—2030, United Nations Office for Disaster Risk Reduction Geneva, Switzerland, 2015.
[83] S. Voigt, T. Kemper, T. Riedlinger, R. Kiefl, K. Scholte, H. Mehl, Satellite image analysis for disaster and crisis-management support, IEEE Trans. Geosci. Rem. Sens. 45 (6) (2007) 1520–1528.
[84] N. Witvorapong, R. Muttarak, W. Pothisiri, Social participation and disaster risk reduction behaviors in tsunami prone areas, PloS One 10 (7) (2015), e0130862.
[85] G. World, Deutschland Leads the Way, 2014. Retrieved from, https://www.geospatialworld.net/article/deutschland-leads-the-way/.
[86] K. Xu, Q. Guo, Z. Li, J. Xiao, Y. Qin, D. Chen, C. Kong, Landslide susceptibility evaluation based on BPNN and GIS: a case of guojiaba in the three gorges reservoir area, Int. J. Geogr. Inf. Sci. 29 (7) (2015) 1111–1124.
[87] E. Zapata-Caldas, G. Hyman, H. Pachón, F.A. Monserrate, L.V. Varela, Identifying candidate sites for crop biofortification in Latin America: case studies in Colombia, Nicaragua and Bolivia, Int. J. Health Geogr. 8 (1) (2009) 29.
[88] L. Zhenmin, M. Kituyi, V. Songwe, World Economic Situation and Prospects 2018, United Nations, New York, 2018.