

# Hazards and Disasters in the Insular Caribbean: A systematic literature review

Tania López-Marrero, Department of Social Sciences and Interdisciplinary Center for Coastal Studies, University of Puerto Rico, Mayagüez, Jenna Hampton, Eric Vergara, Jessica Quiroz, Katarina Simovic & Henry Arevalo, Department of Latino and Hispanic Caribbean Studies, Rutgers University

*E-mail* tania.lopez1@upr.edu

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*Summary:* The Caribbean region is exposed to various natural hazards, including hurricanes, floods, landslides, earthquakes, and volcanoes that make the region's ecosystems and inhabitants vulnerable to loss, dislocation, injury, and death. This paper presents the result of a systematic literature review of peer-reviewed articles published from 1984 through 2012 regarding natural hazards and disasters (and associated concepts such as risk, vulnerability, adaptive capacity, and resilience) in the insular Caribbean. The review intends to address the following questions: Which hazards have been studied the most in the region? What have been the various foci of analysis? Which countries have been studied the most? With this review, gaps and limited information are identified. The results of the review are also discussed within the context of research needs and recommendations to increase knowledge that can be used to assist in advancing hazard and disaster management, adaptive capacity, and vulnerability reduction at different levels.

## *Keywords*

**NATURAL HAZARDS RISK VULNERABILITY CARIBBEAN**

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## **Introduction**

The Caribbean islands share many characteristics that put their populations and ecosystems at risk and increase their vulnerability to natural hazard occurrence. The islands are located in an area that is prone to natural hazards, thus influencing their exposure and associated vulnerabilities. The geographic position of the region within the Atlantic Basin exposes most of the islands to hurricanes and associated hazards (rainfall, winds, and storm surges) from June through November. Floods and mass movements (including land- and mudslides) are also frequent in the insular Caribbean and are triggered by rainfall events during the hurricane season and at other times as well. The tectonic setting of the region results in exposure to earthquakes, tsunamis, and volcanoes. Geographic isolation, small size, limited natural resources, large exposed coastal zones, and high susceptibility to the potential effects of climate change and its associated rise in sea levels are other characteristics that influence the region's vulnerability to natural hazards and put

their populations and ecosystems at risk (Méheux *et al.*, 2007; Mimura *et al.*, 2007; Pelling & Uitto, 2001). Other factors associated with social, economic, and environmental processes at various scales also amplify the vulnerability in the region. Some examples include external economic processes such as economic liberalization and globalization, high levels of urbanization and population densities (particularly in coastal areas), small economies, and environmental changes (Barker, 2012).

It is the combination of these factors that helps to explain why hazards, in many cases, become disasters. Disasters, in turn, cause loss of lives and property, disrupt livelihoods and economies, and in some cases retrocede years of development or put constraints on sustainable development (Méheux, *et al.*, 2007). In the insular Caribbean, for instance, approximately 11,000 people died because of the occurrence of disasters triggered by natural hazards between 1980 and 2009 (López-Marrero & Wisner, 2012). In 2010, a single event, the Haitian earthquake, resulted in 25 times more deaths than all deaths caused by all other hazard types together (hurricanes, floods, mass movements, volcanic eruptions, and droughts) in all countries of the insular Caribbean during the preceding 30 years. The occurrence of disasters also affects the built environment, the agricultural sector, and the ecosystems that provide benefits to the region's inhabitants and that are key to the region's economy (such as the tourism sector) and natural environments.

Within this context, increasing the capacity of human systems and ecosystems to manage hazards better and to cope with and recover from disasters is critical. Knowing what the region, its people, and its ecosystems are exposed to, and understanding the frequency of occurrences and magnitudes of past, current, and future events, along with disaster impacts, are all necessarily elements that can improve people's capacity to take actions in order to resist, cope with, and recover from the occurrences of future disasters (Wisner *et al.*, 2012; Wisner *et al.*, 2004). Identifying the factors that increase people's and ecosystems' vulnerabilities to natural hazards, along with those that facilitate actions to better manage and deal with them, are also critical to identifying ways to reduce vulnerabilities and increase capacities at various levels.

Increasing knowledge, awareness, and skills all constitute part of human capital, which is one of the resources and assets people can draw from to face hazards and better manage risks and disasters (Brooks & Adger, 2005; Eakin & Lemos, 2006; Smit & Wandel, 2006; Yohe & Tol, 2002; Wisner *et al.*, 2012). Published research is one important source of information that serves to increase human capital by acquiring and sharing knowledge about—and from—hazards and disaster occurrence, as well as from the experiences of others facing and managing hazards and disasters. By means of a systematic literature review, this article attempts to summarize what is known about natural hazards and disasters in the insular Caribbean, specifically from the perspective of academic published research.

Systematic literature reviews are used as a method to assess, examine, and summarize the state of knowledge and understanding on a given field, topic, or research question using organized and replicable steps (Ford *et al.*, 2011). They have been used to identify, classify, and summarize key trends in human-environment related research, including,

for instance, climate change vulnerability (Ford & Pearce, 2010), climate change adaptation and planning (Ford *et al.*, 2011; Pearce *et al.*, 2011; Lorenz *et al.*, 2014), carbon accounting (Stechemesser & Guenther, 2012), and urban rivers research (Francis, 2012). In the present article, a systematic literature review was conducted to highlight trends in natural hazard and disaster research in the insular Caribbean during a period of about three decades—between 1984 and 2012. The review also assessed associated concepts such as risk, vulnerability, adaptive capacity, and resilience. It intended to address the following questions: Which hazards have been studied the most in the region? What have been the foci of analysis? Which countries have been studied the most? With answers to these questions we also aim to identify gaps in information and suggest research and information needs.

This project was originally part of a final research project for the course ‘Caribbean Natural Disasters’, which was offered by the lead author at the Department of Latino and Hispanic Caribbean Studies, Rutgers University (Spring 2012). The majority of the search and the initial articles’ classifications (see Method section below) were conducted as part of the requirement of that project. A subsequent search, detailed classification, and the analysis were conducted by the lead author afterward. The students who worked on the research project are the coauthors of the paper.

## **Methods**

### *Article Search and Selection*

The systematic literature review was based on a search conducted using the Web of Science citation index, a search engine that gives access to multiple databases covering the sciences, social sciences, arts, and humanities (Thomson Reuters Group, 2014). Regarding environmental-related research, the citation index database (formally known as the Web of Knowledge) has been used by others to conduct systematic literature reviews (e.g., Berrang-Ford *et al.*, 2011; Ford & Pearce, 2010; Francis, 2012; Lorenz *et al.*, 2014; Pearce *et al.*, 2011; Rist *et al.*, 2012). These authors used the search engine while it was still known as the Web of Knowledge (as opposed to the Web of Science); hence it is cited as such for those articles.

We searched articles published between 1984 and 2012. This time period was selected in order to examine and discuss the results in light of an analysis of disaster occurrence in the region during a similar time period (López-Marrero & Wisner, 2012). We conducted a keyword search using a combination of insular Caribbean country names with (1) different hazard types that occur in the region, and (2) different terms associated with natural hazard, risk, vulnerability, and disaster research (Table 1). In the cases where countries were composed of various islands, the search was done using the country name (e.g. U.S. Virgin Islands) as well as the names of the disaggregated islands (following the U.S. Virgin Islands example, these included Saint Croix, Saint John, and Saint Thomas).

Regional journals were also included as part of the review since some of these journals are not included on search databases such as the Web of Science. The journals included *Caribbean Geography*, *Caribbean Studies*, *Caribbean Journal of Science*,

TABLE 1: *Keywords used in the search process for the systematic literatur review*

Country/Island name	AND	Hazard type
Anegada, Anguilla, Antigua and Barbuda, Bahamas, Barbados, Bonaire, British Virgin Islands, Cayman Islands, Cuba, Curacao, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Netherland Antilles, Puerto Rico, Saba, Saint Croix, Saint John, Saint Kitts and Nevis, Saint Martin, Saint Thomas, Saint Vincent and the Grenadines, Saint Eustatius, Sint Maarten, Saint Lucia, Tortola, Trinidad and Tobago, Turks and Caicos, US Virgin Islands, Virgin Gorda		Hurricane
		Tropical Storm
		Flood
		Earthquake
		Landslide
		Mudslide
		Tsunamis
		Volcano
		Drought
		<b>Topic</b>
	Natural hazard	
	Natural disaster	
	Risk	
	Vulnerability	
	Adaptive capacity	
	AdaptationResilience	

*Journal of Eastern Caribbean Studies*, *Caribbean Journal of Earth Science* (formerly *Journal of the Geological Society of Jamaica*), and *Caribbean Quarterly*. We reviewed the tables of content and articles of these journals and included those articles that were pertinent for our analysis.

The search was conducted April 9–12, 2012 and March 27–April 2, 2014. It resulted in a total of 4,902 records. For each record, we retrieved the article’s title and abstract. The abstracts were then read and evaluated in terms of which articles were to be excluded from the analysis. For this procedure, each coauthor evaluated a similar number of abstracts. Three coauthors reviewed each abstract individually and those who reviewed the same abstracts compared their assessments in terms of the articles to be excluded. After this initial assessment, the lead author—who is from the region and is a specialist in research regarding hazards, disasters, and vulnerability—reviewed all the abstracts to be excluded to assure that they were not related to the purpose of the analysis.

There were three criteria to exclude an article:

(1) *Irrelevant geographic location*: If a study was not conducted in a country or group of countries from the insular Caribbean, or was not related to a geographic location in the region, it was excluded. In some cases, the study areas of various articles had names similar to those of Caribbean islands, but were from other geographic areas. In other cases, the names of Caribbean countries or islands were related to something other than a country. The search for ‘Anguilla’, for example, resulted in the retrieval of many articles about a species of eel, *Anguilla anguilla*, and not the island of Anguilla.

(2) *Irrelevant content*: If the content of the article was not related or relevant to the purpose of our analysis it was excluded. In this case, many of the articles excluded from the analysis were those related to terms like adaptation, vulnerability, risk, and resilience. The use of those terms resulted in articles that discussed situations and processes not related to studies of vulnerability, risks, and disasters within the context of natural hazards. Such cases included, for example, natural adaptation of species and resilience to environmental conditions (from a biological point of view) and human populations at risk in other societal situations (e.g., drug users).

(3) *Repeated article*: If an article appeared more than once in the search, the repeated ones were excluded. We created an MS Excel document with all the articles' titles and authors, sorted them by title, and identified those that were repeated. Of the repeated titles, one was included for analysis and the others were deleted from the dataset and excluded from the analysis.

After this procedure was completed, 3,880 articles were excluded from the analysis, and 1,022 articles were included.

### *Article Categorization*

We read the abstracts of all 1,022 articles included for analysis and categorized them three ways:

(1) The hazard (or hazards) studied: the various geophysical, meteorological, hydrological, and climatological hazards to which the region is exposed.

(2) The focus of analysis: whether the article focused on the physical aspects of hazards or addressed elements of ecosystems or human systems (Table 2). This categorization relates to different related conceptualizations and frameworks of the study of hazards, risk, vulnerability, and disaster (e.g., Adger, 2006; Wisner *et al.*, 2004; Smit & Pilifosova, 2003; Smit & Wandel, 2006; Wisner *et al.*, 2012). Wisner *et al.* (2012), for instance, propose a framework that helps us understand risks and explain why disasters occur when natural hazards affect vulnerable people. In that framework, known as the 'Pressure and Release' model, disaster risk represents the intersection of hazard and vulnerability. In that model, the hazard component addresses elements such as probabilities of occurrence, magnitude, and frequency. Our 'physical' categorization follows this notion of hazard exposure. Vulnerability—being susceptible to loss, damage, and injury from natural hazard exposure—addresses the characteristics of a system that influence people's ability to anticipate, cope with, resist, and recover from the impact of a disturbance or disaster (Adger, 2006; Wisner *et al.*, 2012). These abilities (or otherwise) are expressed both by human systems and ecosystems in the face of disturbances, hazard occurrence, and disasters (Adger, 2006), hence our 'ecosystem' and 'human' categorizations.

(3) The geographic focus: the country or countries from the insular Caribbean that constitute the focus of analysis.

In cases where the abstract provided limited information for the purpose of our categorizations, we examined the entire article. Here again, groups of three coauthors

TABLE 2: *Categorization and description of focus of analysis*

Category	Elements included in each category
Physical	<p>Hazard characteristics including frequency of occurrence, magnitude, intensity, variability, distribution (temporal, spatial)</p> <p>Hazard meteorological or climatological characteristics (e.g., rainfall, wind, temperature, humidity, timing)</p> <p>Reconstruction of past events, climatic history</p> <p>Hazard prediction</p> <p>Bio-physical drivers/triggers of hazard and disaster occurrence</p> <p>Description of methods, tools, or techniques to understand physical characteristics of hazards; methods for risk assessment; modelling</p>
Ecosystem	<p>Effects of hazards in ecosystem structure, functions, composition</p> <p>Hazard impact and damages on ecosystems species</p> <p>Variations in ecosystem's abiotic and biotic conditions after disaster impact</p> <p>Ecosystem response and recovery after disaster impact</p> <p>Methods and techniques to assess and/or simulate ecosystems responses</p>
Human	<p>Determinants of social vulnerability and disasters</p> <p>Factors influencing disaster preparedness, response, and recovery</p> <p>Influencers of risk perception, attitude, behavior towards hazards and disasters</p> <p>Impacts and effects of disasters on human systems</p> <p>Management practices for hazard and disaster impact reduction</p> <p>Adaptation measures</p> <p>Methods and techniques for risk, vulnerability, and capacity assessment</p>

reviewed and categorized abstracts individually and then compared their assessments and agreed on a final categorization. The lead author reviewed all categorized abstracts and made any adjustments needed.

### *Analysis*

The analysis of the categorized data consisted of the generation of basic descriptive statistics (i.e., counts and percentages). Percentages were calculated in terms of the three categorizations: the type of hazard being addressed, the focus of analysis, and the geographic focus. We also noted which articles addressed individual hazards and which addressed two or more hazards in combination; the same was done for the focus of analysis and the geographic focus. In these cases, double counting was allowed. If, for example, one article addressed more than one hazard, then that article was recorded more than once for that classification (for the different hazards addressed). The same was done for the focus of analysis and the country or countries being addressed. Consequently, some of the percentages reported in this article were based on a number larger than that of the number of articles analyzed (1,022).

To determine the relationship between categorizations, we summarized the data in terms of hazard type and focus of analysis, and hazard type and country of analysis. Moreover, to explore the published research temporally, we summarized the data in terms of the number of publications per year for those publications related to hazards from hurricanes, earthquakes, and volcanoes. These three hazards were the most cited in the literature, and they have been the most reoccurring or destructive ones in the region over the last three decades (López-Marrero & Wisner, 2012).

### *Study Delimitations and Limitations*

Our analysis was limited to the insular Caribbean, to articles published in English in scholarly journals during the years 1984 to 2012, and to a search based on the Web of Science Citation Index and a number of selected regional journals.

There are some limitations of the data that we want to point out so that the results and implications of our study are analyzed in the light of these limitations. These include the exclusion of relevant publications that appear in books, book chapters, atlases, and other publications; publications that are published in other languages that are spoken in the region (e.g., Spanish, French, Dutch); and informally published materials (the so-called grey literature) such as technical reports, working papers, and conference proceedings in printed format or other mediums such as the Internet.

Despite the aforementioned limitations and delimitations, we believe that the data and analysis presented in the article provide a good overview of what has been studied and published on the region pertaining to natural hazards and disasters, along with associated concepts of risk, vulnerability, adaptive capacity, and resilience to such events. To our knowledge, a systematic review of academic-level research regarding these topics has not been conducted and published for the region. Such a review will be valuable for researchers and practitioners who conduct work on these topics because it will help them to identify gaps and research needs and to stimulate further and more detailed analysis.

## **Results and Discussion**

### *Hazard Type*

The majority of the examined articles (92 percent) addressed a single hazard, while the remainder of the articles (8 percent) addressed more than one hazard. In the latter case, geologic-related hazards tended to be the ones that were addressed jointly (of the 85 articles that addressed multiple hazards, 20 analyzed earthquakes and volcanoes jointly).

Most published research papers have concentrated on hurricanes, earthquakes, and volcanoes (Figure 1A). Hurricanes, for instance, were addressed in 32 percent of articles (including double counting), followed by 26 percent each in the cases of earthquakes and volcanoes. When specific events were mentioned as a focus of analysis, some events clearly stood out. These were the cases of Hurricane Hugo (1989), Hurricane Georges (1998), Hurricane Gilbert (1988), Hurricane Ivan (2004), the Montserrat volcano, and the Haitian earthquake (2010) (Figure 2).

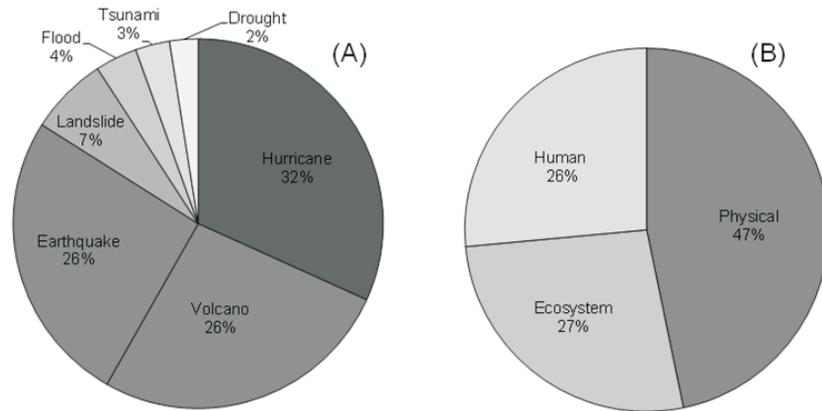


FIGURE 1: Breakdown of articles according to (A) hazard type and (B) focus of analysis

Hugo and Georges were the most cited hurricanes. Hurricane Hugo was directly cited as the focus of analysis in 81 articles (out of a total of 371 articles addressing hurricanes), while Hurricane Georges was the focus of study in 43 articles. By the time it struck the region, Hurricane Hugo was considered one of the 20th century's most severe documented hurricanes to strike the Caribbean Sea and the eastern North Atlantic Ocean (Longshore, 2008). During its passage through the region, it became a category 5 hurricane and generated storm surges on islands such as Antigua, Guadeloupe, Montserrat, the Virgin Islands, and Puerto Rico. The Lesser Antilles were particularly affected by Hugo. In Montserrat, for example, the cotton industry was heavily impacted and there was massive destruction of coastal houses and facilities (Longshore, 2008). In the Greater

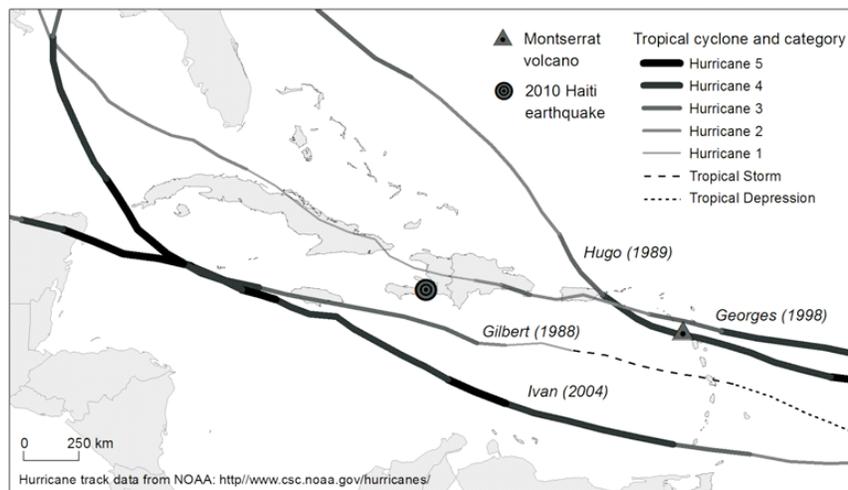


FIGURE 2: Frequently cited hazard-induced disaster events

Antilles, Hugo's impact was particularly noticed in Puerto Rico. There, about a dozen people died because of heavy rains, 50,000 people became homeless, and critical infrastructure and services, including houses, hospitals, hotels, communication systems, and water and electricity systems were damaged (Longshore, 2008). The hurricane also affected El Yunque National Forest, in eastern Puerto Rico, parts of which were either defoliated or uprooted. The damage caused to El Yunque was a major focus for research regarding the ecological consequences of hurricanes on the forest and its subsequent recovery.

About a decade after Hurricane Hugo, Hurricane Georges struck the region, reaching as high as category 4. After Hurricane Jeanne (2004) and Tropical Storm Gordon (1994), Georges is ranked as the third deadliest hurricane affecting the region during the past three decades (López-Marrero & Wisner, 2012). It is estimated that Georges caused approximately 600 deaths in the region due to flash floods and mudslides, the majority of them in the Dominican Republic and Haiti. The hurricane also caused severe damage to the physical infrastructure and water and electric systems in places such as St Kitts and Nevis and Puerto Rico (Longshore, 2008). In Puerto Rico, about 95 percent of the plantain and banana crops were lost during the passage of Georges over the island (Pasch *et al.*, 2001).

Compared to Hugo and Georges, Hurricanes Gilbert and Ivan were relatively less cited hurricanes (Gilbert was directly cited in 13 articles and Ivan in 11). These hurricanes, nonetheless, had great impacts on and caused destruction in some countries of the region. Hurricane Gilbert became an intense category 5 hurricane and brought deaths and devastation to islands such as Jamaica and Guadeloupe (Longshore, 2008). In Jamaica, for example, it left more than 500,000 residents homeless and caused 45 deaths and about one million U.S. dollars in damage. Hurricane Ivan achieved winds of a category 4 system during its trajectory through the region. Ivan passed nearby islands of the southern Caribbean, such as Tobago and the ABC islands (Aruba, Bonaire, and Curaçao), where the occurrence of hurricanes is much less frequent. It caused deaths in Grenada (39), Jamaica (17), and, to a lesser extent (8 in total), the Dominican Republic, the Cayman Islands, Tobago, and Barbados (Franklin, 2006).

The number of articles addressing hurricanes has had a tendency to increase over time (Figure 3A). There are some years when the number of published articles is much higher than for other years, for instance in 1991, and the period of 2009–2011. It is clear, in some of these cases, the influence that major disasters have had in the subsequent increase of published research. The occurrence of Hurricane Hugo in 1989 and the subsequent peak of publications in 1991, for instance, demonstrate this situation. The general trend of increase in the number of published articles over time might reflect the general trend of a slight increase in the occurrence of hurricanes during a similar period of time (Figure 4).

Regarding volcano-related publications, the Soufrière Hills volcano in Montserrat has been a major focus of analysis. Of the total of 309 publications addressing volcano-related research, 129 specifically identified the Montserrat volcano as the case of analysis. The current active period of the Soufrière Hills volcano started in the 1990s,

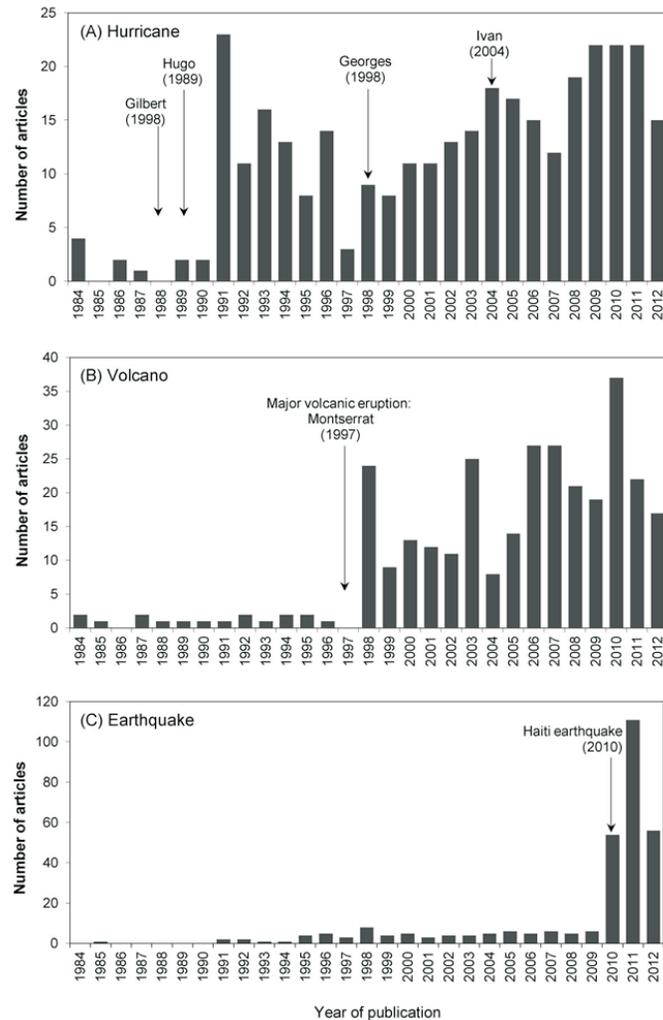


FIGURE 3: Number of articles per year of publications for (A) hurricane, (B) volcano, and (C) earthquake

with significant volcanic eruptions occurring in July 1995 and during the second half of 1997 (Lindsay *et al.*, 2005). In 1997, pyroclastic flows from two main volcanic eruptions destroyed Montserrat's capital city of Plymouth and the W.H. Bramble Airport, both of which had to be relocated to the northern part of the island. Nineteen people died during the events of 1997. These volcanic eruptions also led to Montserrat's largest migratory push, with people leaving for nearby islands such as Antigua and Saint Kitts or for the United Kingdom. As a consequence, Montserrat's population experienced a dramatic decrease from a pre-eruption estimate of 10,500 people to a post-eruption population of

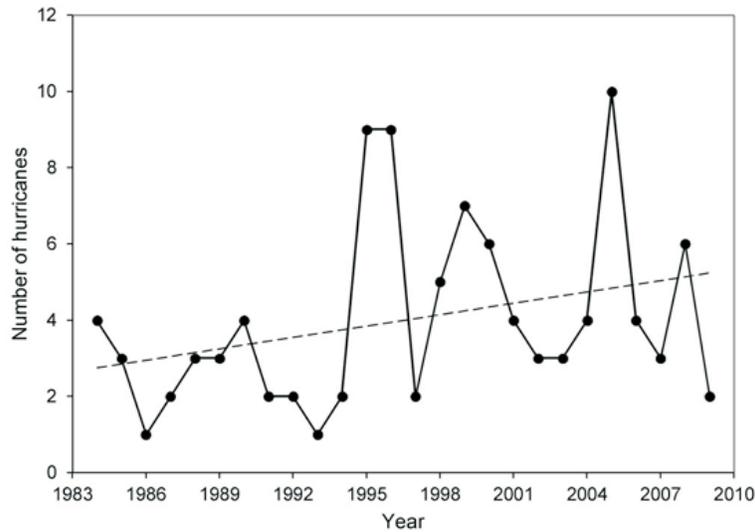


FIGURE 4: Occurrence of hurricanes in the Insular Caribbean region, 1984 through 2009. The dashed line shows the linear trendline

about 4,300 (Lindsay *et al.*, 2005). It is clear that these volcanic eruptions and subsequent volcanic activity have influenced the increase of publications of this hazard type after their occurrences (Figure 3B).

In terms of earthquakes, the Haitian earthquake on January 12, 2010 was clearly the event that most influenced earthquake-related research and publications during the period of study. Out of a total of 301 publications addressing earthquake-related research, this event was directly cited as the focus of analysis in 189 articles. The epicenter of this catastrophic earthquake with a magnitude of 7.0 occurred about 25km southwest from Haiti's capital, Port-au-Prince, with a population of nearly 2 million. Conservative estimates cite at least 217,300 people killed, 300,600 injured, and 2.1 million displaced, with 175,000 homes damaged or destroyed (OCHA, 2012). Other estimates report more than 300,000 people killed. Even with the lowest estimate, the number of people killed in that single event is 25 times greater than the totality of all deaths caused by all other hazard types (hurricanes, floods, mass movements, volcanic eruptions, and droughts) in all countries of the insular Caribbean in a 30-year period, from 1980 through 2009 (López-Marrero & Wisner, 2012). This event has clearly influenced the increase of the number of publications addressing earthquakes since 2010 (Figure 3C).

A relatively lower number of articles addressed the remaining hazard types. Landslides, floods, tsunamis, and droughts were addressed 7 percent, 4 percent, 3 percent, and 2 percent of the time, respectively (Figure 1A). In the case of landslides and floods, these hazards might be considered small- and medium-scale events. Small-scale events, also labeled as 'extensive risks', are defined as 'the widespread risk associated with the exposure of dispersed populations to repeated or persistent hazard conditions of low or moderate intensity, often of a highly localized nature, which can lead to debilitating

cumulative disaster impacts' (UNISDR, 2009:15–16). In the case of the Caribbean, the literature has tended to concentrate on larger-scale events, as was shown for hurricanes, volcanoes, and earthquakes in the region (see the preceding paragraphs). Small- and medium-scale disasters, nonetheless, can have significant impacts, particularly at the local scale, and their impacts can add up to quite surprising total losses (Petley, 2012), hence the importance of addressing them.

Moreover, landslides and floods result from the occurrence of tropical storms and cyclones, hence they are oftentimes grouped with hurricanes. Most of the deaths attributed to hurricanes in the region have resulted from floods and mudslides. Nonetheless, floods and mud- or landslide events are not events exclusively resulting from hurricanes. Some of them have resulted from intense rainfall outside of the hurricane season. One example is the flood event in 2004 in Jimaní in the Dominican Republic close to that country's border with Haiti. The flood occurred during May from a low-pressure system that brought more than 500mm of rainfall on the Riviere Soliette watershed (Brothers *et al.*, 2008), a watershed with most of its area in Haiti. The disaster resulted in the deaths of at least 1,000 people, and about 1,600 missing (Gubbels & Brakenridge, 2004). While tropical cyclones have dominated the research and literature regarding climatic hazards, other climatic hazards such as nontropical heavy rains and orographic precipitation, along with their effects and potential impacts over the region, should not be neglected (Gamble, 2004).

Drought and tsunamis, in contrast, have been referred to as the 'neglected' and 'forgotten' hazards (Gamble, 2014; Puerto Rico Seismic Network, 2011). The slow onset nature of drought can be a factor that influences the relatively low number of publications addressing this hazard type. A slow onset disaster or emergency is defined as one that 'do not emerge from a single, distinct event but one that emerges gradually over time, often based on a confluence of different events' (OCHA, 2011:3). In the case of drought in the Caribbean, particularly, some climate change scenarios predict drier climates (Taylor *et al.*, 2012). This situation can increase the frequency of droughts and their impacts in the region, including, for instance, impacts to the agricultural sector and to small-scale farmers (Barker, 2012) and on the availability of fresh water and its management (Cashman *et al.*, 2010). Hence, it is important to increase the number of research and publications about this type of hazard in the region.

The low frequency of tsunami occurrence might be a factor that has resulted in the relatively low number of publications regarding this hazard type. Tsunamis can (and have), however, create great damage, disruption, and death in the region, as was the case of the tsunami in Puerto Rico in 1918. An event like that today, particularly with the high density of people and the location of infrastructure in coastal areas, could be devastating. Addressing this hazard type from multiple perspectives is also crucial.

### *Focus of Analysis*

Regarding the focus of analysis, the majority of the 1,022 articles (97 percent) analyzed physical, ecosystem, and human aspects of hazards and disasters individually. Conversely, a small fraction of the articles (3 percent) assessed the topics in combination. In

this case, the joint combination of ‘physical’ and ‘human’ aspects was the one that occurred the most (14 articles of a total of 28 articles addressed these two categories in combination).

The ‘physical’ aspects of hazard and disaster have dominated the published research in the region; elements associated with this category were addressed 47 percent of the time (Figure 1B). Research focusing on aspects regarding ecosystem and human systems has been relatively less published; each of these categories was addressed about one-quarter of the time. Understanding natural hazards’ exposure in the region and their associated physical elements (such as potential occurrence, magnitude, frequency, and speed of onset) are certainly important to understand the vulnerability of people and ecosystems to hazard occurrence and future potential occurrences. The high number of publications on the physical aspects of hazard and disaster, consequently, provide for such understanding. Exposure (and its associated physical elements), however, is just one of the determinants of vulnerability; the adaptive capacity and sensitivity of the systems (humans and ecosystems) that are affected by hazards are the other two determinants (Polskyet *al.*, 2007; Smit & Wandel, 2006). At the moment, the relatively low number of publications on aspects regarding humans and ecosystems limits our understanding of the process that influences their vulnerability. This, in turn, can limit the development of practical applications and strategies to increase the capacity of human systems and ecosystems to better withstand current and future hazards and disasters.

#### *Hazard Type and Focus of Analysis*

When comparing hazard type and focus of analysis, a difference is noted in terms of how each type of hazard has been addressed (Figure 5). Hurricanes and drought, for instance, have been studied most from an ‘ecosystem’ point of view. Seventy percent (70 percent) and 67 percent of all published articles on hurricanes and droughts addressed the hazard from that perspective, respectively. The majority of the published articles about volcanoes and tsunamis addressed these hazards from a ‘physical’ point of view (about 88 percent of all articles addressing these hazard types in each case). Earthquakes and floods were the hazard types most articles addressed in terms of the ‘human’ category. For earthquakes, 55 percent of all articles addressing this hazard type focused on some human aspect. In this case, specifically, the majority concerned the earthquake in Haiti in 2010. Regarding floods, 51 percent of the flood-related articles focused on the ‘human’ category. Landslide-related articles tended to focus on the physical aspects of those hazards (51 percent of those articles), but some of them (31 percent) addressed the ‘ecosystem’ category.

There are some hazards for which the ecosystem and human focus of studies have been minimal. For instance, only 3 percent of the volcano-related research has been addressed from an ‘ecosystem’ point of view, while 5 percent and 8 percent of the articles on tsunamis have addressed the ‘ecosystem’ and ‘human’ categories, respectively. In the case of earthquakes, less than 1 percent of the articles related to that hazard addressed elements associated with ecosystems.

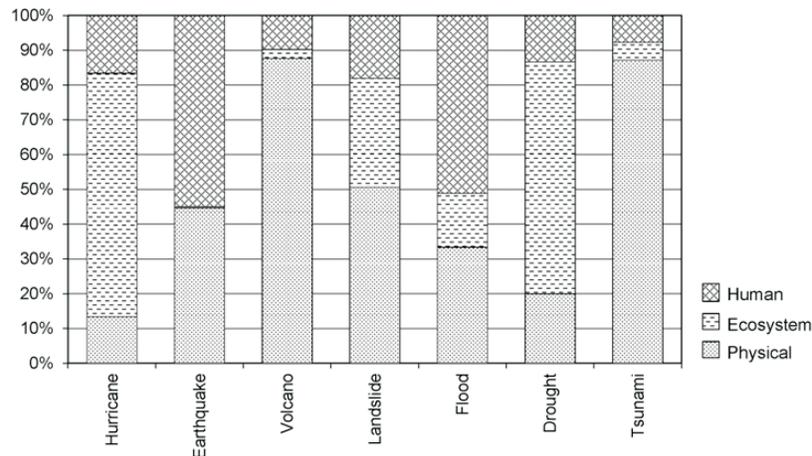


FIGURE 5: Proportion of articles addressing hazard types and focus of analysis

### *Geographic Focus*

Geographically, most of the published studies were about Puerto Rico, Montserrat, and Haiti, with 21 percent, 20 percent, and 19 percent of the articles on those countries, respectively (Figure 6). In the case of Puerto Rico, there has been a relatively large number of articles published addressing hurricanes (see the next section). Several factors may have influenced this finding. The recurrent frequency of occurrence of tropical cyclones, along with the relatively high number of the published articles about hurricanes (refer to the earlier section entitled ‘Hazard Type’) may partly explain the high number of publications in this case. Additionally, Puerto Rico has well-established long-term ecological research stations that produce a high number of publications (for instance, on the ecological aspects of hurricanes and associated hazards such as landslides). This research is conducted by local and foreign researchers, particularly those from the United States. Moreover, many of the peer-reviewed published research about Puerto Rico is published in English, which was the language of the articles included in the analysis.

In the case of Montserrat, the presence of the Soufrière Hills active volcano and the major volcanic eruptions and pyroclastic flows of the 1990s (most notably in 1995 and 1997) have stimulated many research initiatives that are mostly oriented to understanding the physical aspects of volcanoes (see Figure 5) and volcanic eruption in Montserrat, more specifically, and in the region, more generally. Ultimately this type of research aims to provide information for better prediction and tools to enable better preparation in the face of volcanic activity.

Regarding Haiti, most of the published research is related to the occurrence of earthquakes, particularly to the occurrence of the earthquake of 2010. When we consider that 223 articles directly cited Haiti as a focus of analysis, 208 articles studied specifically earthquake hazard in Haiti (see the next section), and 189 articles specifically identified

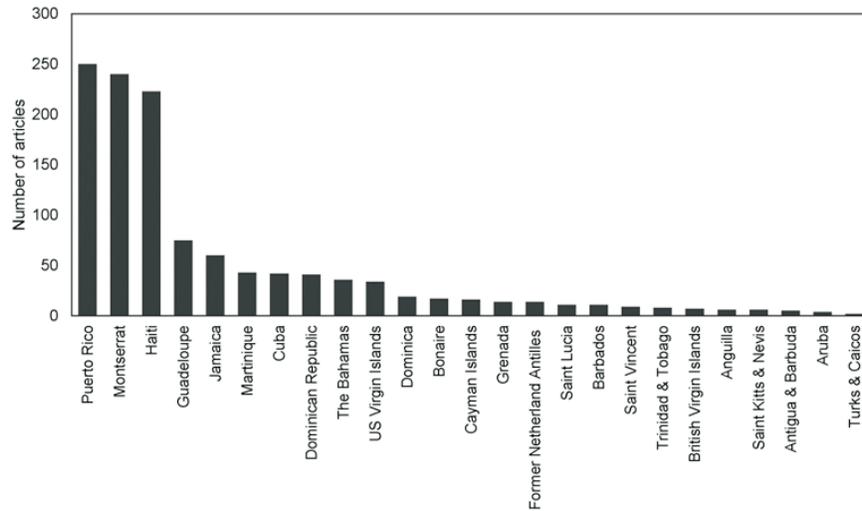


FIGURE 6: Number of articles addressing different countries

the earthquake of 2010 as the focus of analysis, we can conclude that if the earthquake of 2010 had not occurred, then Haiti would have minimum published research (a situation that would position the country on the right-most end part of Figure 6). A closer examination of the topics addressed within the ‘human’ category revealed that in many cases the published research examined and documented the experience of outsiders and their practices while assisting the country and its population in the aftermath of the event. Certainly, experiences and lessons learned from the Haitian earthquake can provide insights on similar cases elsewhere. However, it is unfortunate that not much work addressed the Haitian population, more specifically, their level of vulnerability, causes of sensitivity, and lack of preparedness and capacity to cope and recover from such events. Given the fact that Haiti has been identified as the most vulnerable country in the Western Hemisphere (Pelling & Uitto, 2001), it is clear that it is critical to understand the processes that create and exacerbate vulnerability and to identify and propose practical actions and initiatives to reduce vulnerability and enhance capacities to deal with hazard events.

Some countries, such as Guadeloupe, Jamaica, Martinique, Cuba, the Dominican Republic, the Bahamas, and the U.S. Virgin Islands, were addressed only in 3 percent to 6 percent of the articles. Published research on other countries, however, was even more minimal. This was the case, for instance, of Antigua and Barbuda, Aruba, and Turks and Caicos, with less than 1 percent of the reviewed articles addressing these countries. In the case of Cuba, the success of the Cuban system in terms of hurricane risk management and its emphasis on saving lives has resulted in a relatively low number of people killed, despite the relatively high number of hurricane-related disasters reported in that country

(López-Marrero & Wisner, 2012). Yet, the number of published research on Cuba is slight.

Finally, the majority of the published research addresses countries individually. Of the total 1,022 articles analyzed, 92 percent addressed countries on a one-by-one basis, while the remaining 8 percent addressed two or more countries together. In those articles addressing multiple countries, there is a clear trend tied to political connections between the countries under discussion. For example, 13 articles (of a total of 86 addressing multiple countries) focused on Puerto Rico and the U.S. Virgin Islands, while 8 focused on the French Caribbean, specifically Guadeloupe and Martinique. The occurrence of two countries on a single island, as is the case of Hispaniola, which is composed of Haiti and the Dominican Republic, also was noted in articles that jointly addressed multiple countries. Additionally, the occurrence of regional processes also resulted in articles that addressed multiple countries. For instance, countries from the northern Caribbean associated with tectonic processes related to the interaction of the Caribbean and North American Plates were addressed in conjunction. The same occurred with countries from the volcanic arc of islands of the Lesser Antilles.

### *Geographic Focus and Hazard Type*

Hurricane was the hazard type that tended to be the focus of analysis in relatively more countries; it constituted the focus of analysis of at least half the articles in 10 countries (Figure 7). The Bahamas, the Cayman Islands, and Puerto Rico were the countries with more hurricane-related published research, with 86 percent, 72 percent, and 59 percent of their total number of articles, respectively.

In terms of earthquakes, Haiti was the country with more articles published for this hazard (89 percent), and this was due to the earthquake of 2010. Cuba and Turks and Caicos had about 50 percent of their articles on earthquakes. While these two countries have reported very little earthquake-induced disasters (López-Marrero & Wisner, 2012), the tectonic context of the interaction between the Caribbean and North American Plates occurs close to these countries (in the case of Cuba in the southern part of the country). The study of earthquakes in these cases, particularly the physical aspects, is noted and provides for understanding earthquake-related hazards and risks in the region. Regarding volcanoes, another geologically induced hazard, the island of Montserrat had a high percentage of its articles (87 percent) addressing that hazard type. This is to be expected because of the major eruptions that occurred during the second half of the 1990s and the continued volcanic activity. Martinique and St Vincent also had a relatively large number of articles addressing volcanoes (55 percent and 46 percent, respectively).

Compared to hurricanes, earthquakes, and volcanoes, landslides, floods, drought, and tsunamis were addressed relatively less often in the different countries. There are a few cases, however, where these hazards constituted at least one-third of the articles from some countries. This was the case for tsunamis in Aruba and the British Virgin Islands, and landslides in St Lucia.

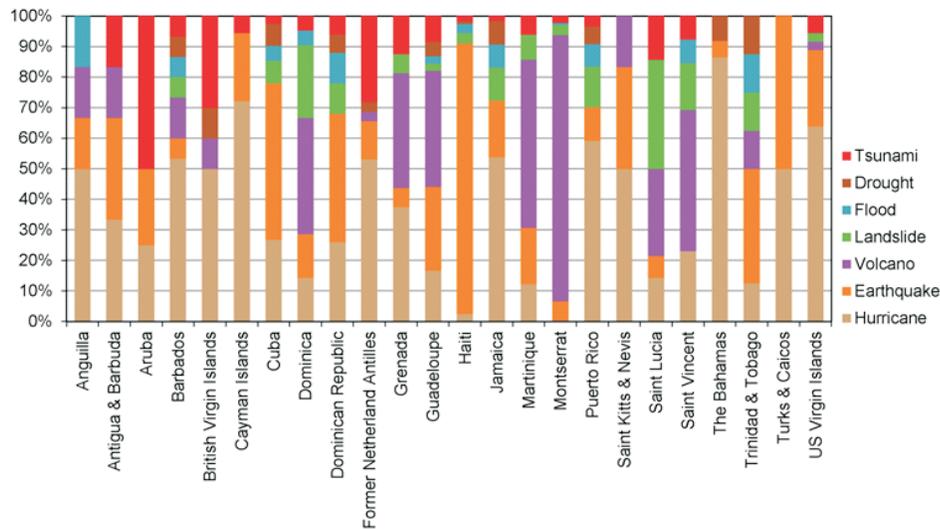


FIGURE 7: Proportion of articles addressing different countries and hazard types. (Color figure available on the article’s digital version)

### Concluding Remarks and Recommendations

In this article we provide a summary of the findings of a systematic literature review about academic research published during 1984–2012 that addressed topics of natural hazards, disasters, and associated concepts in the insular Caribbean. We aimed to answer three general questions through the findings of our review: Which hazards have been studied the most in the region? What have been the foci of analysis? Which countries have been studied the most?

Hurricanes, earthquakes, and volcanoes have been the hazard types that most published research papers have concentrated on. When specific events were the focus of analysis, the relatively large-scale events that resulted in widespread and immediate impacts were the ones addressed more often: for instance, major hurricanes (Hurricanes Hugo and Georges), explosive volcanic activity (the Soufrière Hills volcano in Montserrat), and the earthquake in Haiti in 2010. Additionally, the tendency was to address hazards individually; studies addressing multiple hazards were limited.

The physical aspects of hazards and disasters have tended to dominate the research and, consequently, the published articles. These elements include, for example, frequency of occurrence, intensity, severity, and variability. This information provides useful insight regarding the different hazard exposures to which the region’s populations and ecosystems are prone. Exposure is one of the determinants of vulnerability, and, in this sense the information is a valuable tool to address vulnerability. But vulnerability is not determined solely by exposure; systems’ sensitivities and adaptive capacities are also

part of the equation and assessment. These two determinants concern human systems and ecosystems. The results from the review indicate that studies about these two components (humans and ecosystems) are comparatively fewer in number. The exception to this trend was the large focus on human aspects regarding the Haitian earthquake of 2010. As with hazard types, the different foci of analysis were generally addressed independently from one another.

Regarding the geographic distribution of where studies have been conducted the most, three countries stand out: Puerto Rico (mostly associated with hurricane-related studies focusing on the characteristics and processes of ecosystems), Montserrat (regarding volcanoes and associated physical elements), and Haiti (regarding mostly earthquakes, with emphasis on the earthquake of 2010, and addressing mostly human elements associated with hazard and disaster occurrence). In the case of geographic focus, the majority of the research was conducted in individual countries, as was the tendency in the previously described categorizations.

Based on the findings of the systematic literature review, a number of research gaps or limited information, information needs, and research needs have been identified. From these, some recommendations are suggested. There is a need to increase research and the number of publications regarding those hazards less represented in the literature but that can result in great impact, loss, and damage in the region. These include the so-called small- and medium-scale events (like floods and landslides), slow onset events (like droughts), and less frequent disasters (such as tsunamis). More studies should also address the relationship between, and the interactions of, multiple hazards. At the moment, most of the published research focuses on hazards and disasters on a one-by-one basis.

There is a need for studies that address the multifaceted nature of hazards and disasters, specifically the interactions between the physical aspects of events and the aspects associated with human systems and ecosystems that ultimately are the factors by which hazards become disasters. This requires more collaboration between researchers from various disciplines from the social and natural sciences.

There is a need to document the experience of countries that are highly exposed to hazards and that have had a high number of disasters, yet for which there is limited information about what constitutes their vulnerabilities, how they manage hazards, and what factors facilitate or constrain capacities, among others. At the moment, most research has concentrated on three countries: Puerto Rico, Montserrat, and Haiti. In the case of Haiti, the high number of publications was in response to the earthquake of 2010.

More case studies, at different scales of analysis, are needed. Risk management and adaptive capacity research emphasize the need to contribute to practical initiatives that address and improve the capacities of communities and individuals exposed to natural hazards to deal with them. For this we first need to identify the situations, conditions, needs, and opportunities of those that are more at risk. Case studies provide a valuable tool to explore these elements. There is also a need for comparative studies and publications that address and compare multiple countries. At the moment, most of the published research has addressed countries on a one-by-one basis. Comparative studies allow

people to learn from each other and to identify best practices (or otherwise) for hazard and disaster management. There are various barriers that can limit the development of comparative studies in the Caribbean (e.g., financial resources, language barriers, countries with different political status, and limits posed on collaborations). Yet, we must find ways of overcoming these barriers and promote more collaboration.

Detailed analysis of data is also needed. For instance, subsequent studies with more in-depth analysis of the content of the articles within the three general categorizations presented in this article can shed more light for more specific recommendations for future research and applications. For example, the 'human' category can be subdivided into more detailed categories (e.g., the sensitivity determinant of vulnerability or adaptive capacity, the phase of disaster management, and the scale of the studies).

Finally, future research can concentrate on assessments of past research and the impact of publications. For example, how has published research contributed to a better understanding of exposures in the region? Are systems better prepared to withstand hazards and disasters? This aspect is a call to explore the practicality of academic research, a difficult and sometimes contested task, but a necessary one.

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