Comprehensive Diagnostic of Gender Sensitive Innovative Disaster Risk Financing Instrument for Resilience Building

Risk Audit Report

August 8, 2022

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v3, 8 August 2022

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1 Introduction

1.1 Purpose

This Risk Audit report quantifies risk to a range of hazards through different exposure and vulnerability lenses across the Borrowing Member Countries (BMCs) of the Caribbean Development Bank (CDB). Our assessment of risk across the BMCs focuses specifically on risk to natural hazards, primarily at the national level. This helps to build a regional view of risk across the BMCs and allows for relative comparisons – a valuable input to decisions surrounding investment and funding priorities. In doing so, it provides a view on the level of risk that can be managed through disaster risk reduction, as well as residual risk which demands complementary emergency response and recovery capabilities.

In Section 2, we review the outputs of probabilistic hazard modelling studies that have been conducted across the region to date. Rather than replicate prior hazard modelling efforts, our focus is to summarise and harmonise existing datasets to provide a refreshed view of hazards across the BMCs. Our analysis uses tropical cyclone wind, earthquake shaking, drought, and excess rainfall hazard information to develop a view of risk across the BMCs. The most appropriate analytical approach varies for each hazard and depending on the availability of relevant data. Where existing risk modelling work is limited, we have sought to complement quantitative analysis with qualitative information. In doing so, we provide a regionally consistent assessment of the relative hazard intensities faced by the BMCs.

Following the hazard assessment, Section 3 begins with a review of previous approaches to assessment of exposure and vulnerability of people and assets to disaster risk. We adopt an indicator-based approach since this allows for consistent comparisons across the BMCs. This review is used to create a shortlist of indicators / indexes (where an index is defined as a metric comprising two or more indicators) covering the core facets of exposure and with specific attention towards capturing the most disaster-vulnerable groups across the BMCs. Gender-related indicators used in our analysis include: percentage of the total population that is female; sex-disaggregated life expectancy; ratio of female-to-male labor force participation rate; sex-disaggregated secondary school enrolment; and proportion of seats held by women in national parliaments. Indicators relating to other vulnerable groups include: percentage of population aged under 15; percentage of population aged over 65; and educational expenditure as a percentage of GDP. This assessment is used to identify the relative levels of exposure and vulnerability across the region.

Section 4 considers the distinction between risks that can be reduced and approaches to manage residual risk. Various disaster risk management tools are introduced and their effectiveness for managing risks of different return periods and associated intensities is discussed. Regional-level insights are important for the prioritisation of disaster risk funding and the development of regional-level strategy. However, selection of the most appropriate risk management approaches will ultimately be shaped by sub-national information on hazard, exposure, and vulnerability. The Coalition for Climate Resilient Investment (CCRI) is discussed as an example of a sub-national methodology that can be deployed to prioritise disaster risk management interventions at this scale.

Finally, this report concludes by summarising the analysis and considering the collected hazard, exposure, and vulnerability information to devise a regional view of disaster risk.

1.2 Key terms

Key terms used throughout this report are defined as follows:[1]

- **Risk:** “Risk” is a term that has been defined in various ways depending on its application, which varies widely from engineering, to sociological, psychological, and environmental spheres (among many others). Across the disaster risk management space, the widely accepted definition of risk is understood to be the product of three components, hazard, exposure, and vulnerability.

- **Residual risk:** The disaster risk that remains in unmanaged form, even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained.

- **Hazard:** The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In the context of this report, the term hazard usually refers to natural physical events or trends or their physical impacts.

- **Exposure:** The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by one or more hazards.

- **Vulnerability:** The propensity or predisposition of a system to be adversely affected by one or many given hazard(s). As described above, vulnerability encompasses a system’s sensitivity or susceptibility to harm and lack of capacity to cope and adapt. The conceptualisation of vulnerability used in this report follows that of the IPCC’s Fifth Assessment Report[2], which articulates vulnerability as a function of two related components, adaptive capacity and sensitivity.

- **Adaptive capacity:** The ability of systems (including communities and environmental systems), institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. Developing adaptive capacity involves undertaking research, monitoring data and relevant information sources, awareness raising, capacity building, and creating a supportive institutional framework.

- **Sensitivity:** The degree to which a system is affected, either adversely or beneficially, by variability or change.

[1] UNDRR. 2022. Terminology. Accessible at: https://www.undrr.org/terminology
[2] IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

2 Hazard modelling

2.1 Review of historical hazard events across the BMCs

Over the period 2000-2019, the Latin America and the Caribbean region was the second-most disaster-prone region in the world, with an estimated 145 million people impacted by droughts, earthquakes, floods, tropical cyclones, and volcanic activity, with landslides, extreme temperatures, and wildfire also posing a threat.[3] Furthermore, trends in disaster frequency and/or severity from the recent past are set to worsen given that five of the top ten countries most affected by climate change globally are in the Caribbean.[4]

The 7.2 magnitude earthquake that struck Haiti in August 2021, followed by severe and excess rainfall in the wake of Tropical Depression Grace, underscores the multi-peril threat faced by many Caribbean states. Table 1 shows the range of hazards that Caribbean countries are exposed to. The relative threat posed by each hazard varies both between and within countries depending on the hazard gradient (the spatial rate of change in the intensity of the hazard). This report focuses on natural hazards.

Natural Hazards	Anthropogenic Hazards	Biological / Health Related Hazards
Meteorological and Hydrological: ▪ Tropical cyclones (tropical storms and hurricanes) ▪ Rainfall, including severe rainfall events ▪ Lightning ▪ Extreme heat and increasing temperatures ▪ Floods ▪ Drought ▪ Sea-Level rise **Geohazards:** ▪ Earthquakes ▪ Mud Volcanoes ▪ Tsunamis ▪ Submarine volcanic eruptions (associated with Kick'em Jenny in some southern islands) ▪ Landslides (though can be triggered / worsened by human activities) **Environmental:** ▪ Land degradation ▪ Coastal erosion ▪ Soil erosion ▪ Sahara dust ▪ Alien invasive species (e.g., Sargassum) ▪ Coastal inundation/flooding ▪ Coral reef degradation	**Chemical:** ▪ Oil spills ▪ Transboundary movement of hazardous materials/ wastes **Technological** ▪ Road, aviation and marine and nautical accidents ▪ Industrial accidents ▪ Infrastructure failures ▪ Aging infrastructure ▪ Fires (bush and forest fires) **Societal:** ▪ Fires ▪ Terrorism ▪ Cybercrimes/cyber security ▪ Societal unrest	**Biological:** ▪ Human disease outbreaks, epidemics, pandemics ▪ Animal (livestock) and plant (agricultural) epidemics ▪ Other biological/physical hazards such as poisoning, eutrophication, air pollution

Table 1 Hazards that the BMCs are exposed to.[5]

[3] OCHA. 2019. Natural Disaster in Latin America and the Caribbean. Accessible at: https://reliefweb.int/sites/reliefweb.int/files/resources/20191203-ocha-desastres_naturales.pdf
[4] Global Facility for Disaster Reduction and Recovery. Latin America and Caribbean. Accessible at: https://www.gfdrr.org/en/region/latin-america-and-caribbean-lac
[5] International Science Council and UNDRR, 2020. Hazard Definition and Classification Review: Technical Report. Accessible at: https://council.science/wp-content/uploads/2020/06/UNDRR_Hazard-Report_DIGITAL.pdf

The most commonly experienced hazards across the BMCs are tropical cyclone wind and storm surge, flood inundation, and earthquake shaking, and drought. Additional hazards that contribute to the risk profile of certain countries across the region include landslides (e.g., Saint Lucia, Dominica), and volcanic activity (e.g., Dominica, Montserrat, Saint Lucia, Saint Vincent and Grenadines)[6]. Table 2 summarises the number of earthquake, excess rainfall (cyclonic and non-cyclonic), cyclonic wind, and drought events that have occurred over the most recent decades across the BMCs.

Country	Earthquake (1900 - 2022)	Cyclonic Excess Rainfall (1998 – 2022)	Non-cyclonic Excess Rainfall (1998 – 2022)	Cyclonic Wind (1990 – 2022)	Drought (1980 – 2022)
Anguilla	4	10	2	59	1
Antigua and Barbuda	24	14	0	52	4
Bahamas	0	39	2	40	1
Barbados	0	11	0	51	6
Belize	2	22	1	21	2
Bermuda	0	35	0	22	2
British Virgin Islands	11	24	2	27	1
Cayman Islands	10	21	0	28	3
Dominica	17	15	0	27	4
Grenada	2	8	0	27	3
Guyana	4	0	n/a	0	3
Haiti	17	46	32	19	2
Jamaica	6	28	8	18	6
Montserrat	1	22	0	18	n/a
Saint Kitts and Nevis	4	13	0	25	2
Saint Lucia	1	9	1	14	3
Saint Vincent and the Grenadines	1	11	2	19	3
Suriname	0	0	n/a	0	5
Trinidad and Tobago	22	14	7	20	5
Turks and Caicos Islands	0	21	0	30	n/a

Table 2 Number of historical natural hazard events that have had a substantial impact on the BMCs. Event counts obtained from CCRIF Risk Profiles (2019) for all countries except Guyana and Suriname. Earthquake includes all events of magnitude 5+, occurring within 30 km of land; Cyclonic Excess Rainfall includes heavy rainfall events associated with named storms; Non-cyclonic rainfall broadens this to consider intense rainfall events not associated with cyclonic systems; Cyclonic Wind includes all events where high winds resulted in notable damages. Counts updated through desk-based research for the period 2019 – 2022.

[6] CDEMA Country Profiles. Accessible at: https://www.mona.uwi.edu/cardin/country-profiles

Table 2 demonstrates the recurrent nature of these hazards across the region. An appreciation of the frequency and severity of recent natural hazard events is important in the broader context of appraising disaster risk financing mechanisms because of the role that historical events have in shaping risk management and budgetary priorities.

There have been relatively few damaging earthquake events across the Caribbean. Haiti stands out as suffering by far the greatest impacts, with the August 2021 event (magnitude 7.2) causing over 2,000 fatalities, and the January 2010 event (magnitude 7.0) causing over 200,000 fatalities, widespread destruction, and over USD 10 billion of losses. Events in October 1952 (magnitude 6.2), and in 1947 are also reported to have causes fatalities and losses. Other BMCs that have suffered earthquake related losses, though on a smaller scale, include Jamaica (events in 1907, January 1993, and January 2020), Trinidad and Tobago (magnitude 6.7 event in April 1997), Antigua and Barbuda (events in October 1974 and November 2004), and the Cayman Islands (events in January 1993 and January 2020).

Hurricanes are among the most frequent hazard events experienced throughout the region. Over the period 1991 – 2020, the average Atlantic hurricane season has included 14 named storms, 7 hurricanes, and 3 major hurricanes (Category 3 or above)[7]. The storms themselves may vary considerably in terms of their characteristics and the drivers of loss, for instance, some storms are associated with intense rainfall, while others are damaging primarily as a result of high winds.

Extreme tropical cyclone winds are the major driver of losses across the Caribbean. The 2017 Atlantic hurricane season is among the costliest on record with Hurricanes Irma and Maria each resulting in USD >1 billion losses spread across numerous Caribbean countries. Maria caused extreme damage partly due to the rapidity of its intensification, from being classified as a hurricane on 17 September, to a category 5 hurricane the following day. Impacts were especially severe in Dominica, Barbados, Saint Lucia, and Turks and Caicos. Other notable events include Ivan (2004) which caused major damage and economic losses in the Cayman Islands (USD >2 billion), Grenada (USD >900 million), and Jamaica (USD >350 million), with additional impacts in Barbados and several other islands; Dorian (2019) which "stalled" as it made landfall over the Bahamas, causing approximately USD 3.5 billion of losses, 65 fatalities, and affecting 29,000 people; Matthew (2016) which resulted in >500 fatalities and USD >2.7 billion losses in Haiti; Sandy which affected >500,000 people across Haiti and Jamaica; Gilbert (1988) which caused around USD 800 million of losses across Jamaica, Haiti, and Saint Lucia; and Wilma 2005, responsible for around USD 700 million of losses across The Bahamas, Bermuda, Haiti, and Jamaica. Andrew (1992) and Laura (2020) also caused an excess of USD 100 million losses.[8]

Most tropical cyclone events also bring intense rainfall, resulting in severe flooding, particularly in association with storm surge inundation in coastal areas. Heavy rain also triggers landslides. For most of the storms cited above, rainfall caused additional damage to that caused directly by wind, particularly for those BMCs not on the direct track of the storm. But other storms feature rainfall as the predominant driver of damage; Tomas (2010) is known as a particularly "wet" storm, responsible for significant losses in Saint Lucia and Barbados. Erika (2015) is also noted as a relatively weak storm that only reached Tropical Storm status, and yet as a result of intense rainfall cause approximately USD 500 million of

[7] https://www.nhc.noaa.gov/climo/#bac
[8] Figures quoted in this paragraph are collated from the CCRIF Country Risk Profiles. Figures are approximate only, and based on estimates shortly after the event impacts.

losses in Haiti and Dominica. Additional storms associated with notable rainfall-driven impacts include Georges (1998), Lenny (1999), Keith (2000), Frances (2004), Jean (2004), and Maria (2017).[9]

Though typically less common than cyclone-related excess rainfall, some of the BMCs are also exposed to non-cyclonic excess rainfall. For example, Haiti suffered USD >2 billion of losses occurring in the year 2006 as a result of persistent heavy rainfall. Located outside of the tropical cyclone basin and home to several major river systems, Guyana and Suriname are very exposed to non-cyclonic flooding. It is difficult to quantify the number of historical flooding events that these countries have experienced, though especially severe flooding occurred in Guyana in November 2013, November 2014, June 2015, July 2015, May 2017, November 2020, May 2021, June 2021, and June 2022. Located at the mouth of the Demerara River, Guyana's capital city, Georgetown, has experienced repeated severe flooding events. Major flooding events occurred in Suriname in June 2021 and June 2022. Paramaribo is located at the mouth of the Suriname River where the concentration of people and assets has resulted in numerous major loss events in the past.[10]

Drought "events" are slower-onset and longer-lived than the other natural hazards outlined in Table 2. Drought can be defined in various ways, according to drivers of drought (which may be climatic but also socioeconomic or political), and the measurable impacts (for instance on vegetation). Common types of drought include: meteorological (relates to the amount of rainfall in a given period compared to the long-term average), hydrological (which focuses on surface and sub-surface water supply), and agricultural (which is based on the response of vegetation to a lack of water availability). Drought across the Caribbean is particularly associated with El Niño Southern Oscillation (ENSO) events. For instance, the year 2015/16 was characterised by a strong El Niño signal, with drought impacts felt in Antigua & Barbuda, Barbados, Belize, British Virgin Islands, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, and Trinidad and Tobago. The impacts varied between countries, but included increased incidence of bushfires, water shortages, decreased agricultural production, hot weather warnings (including for human health), interruption to electricity generation, and impacts to the tourism industry. Additional drought periods include 2009-2010 (Antigua & Barbuda, The Bahamas, Barbados, Bermuda, Dominica, Jamaica, Guyana, Grenada, Saint Lucia, Saint Vincent and Grenadines, Trinidad and Tobago), and 2019-2020 (Barbados, Belize, Saint Lucia, Saint Vincent and Grenadines).[11]

2.2 Review of probabilistic hazard modelling studies across the BMCs

The Caribbean has been the subject of numerous regional initiatives seeking to quantify the frequency and severity of environmental natural hazards as part of broader disaster risk assessment and management efforts (Figure 1). Much of this previous work remains valuable and relevant in characterising present-day natural hazards. Rather than replicating the outputs of previous projects, our approach focuses on collating and analysing existing probabilistic hazard modelling studies.

[9] Figures quoted in this paragraph are collated from the CCRIF Country Risk Profiles. Figures are approximate only, and based on estimates shortly after the event impacts.
[10] Ibid.
[11] Ibid.

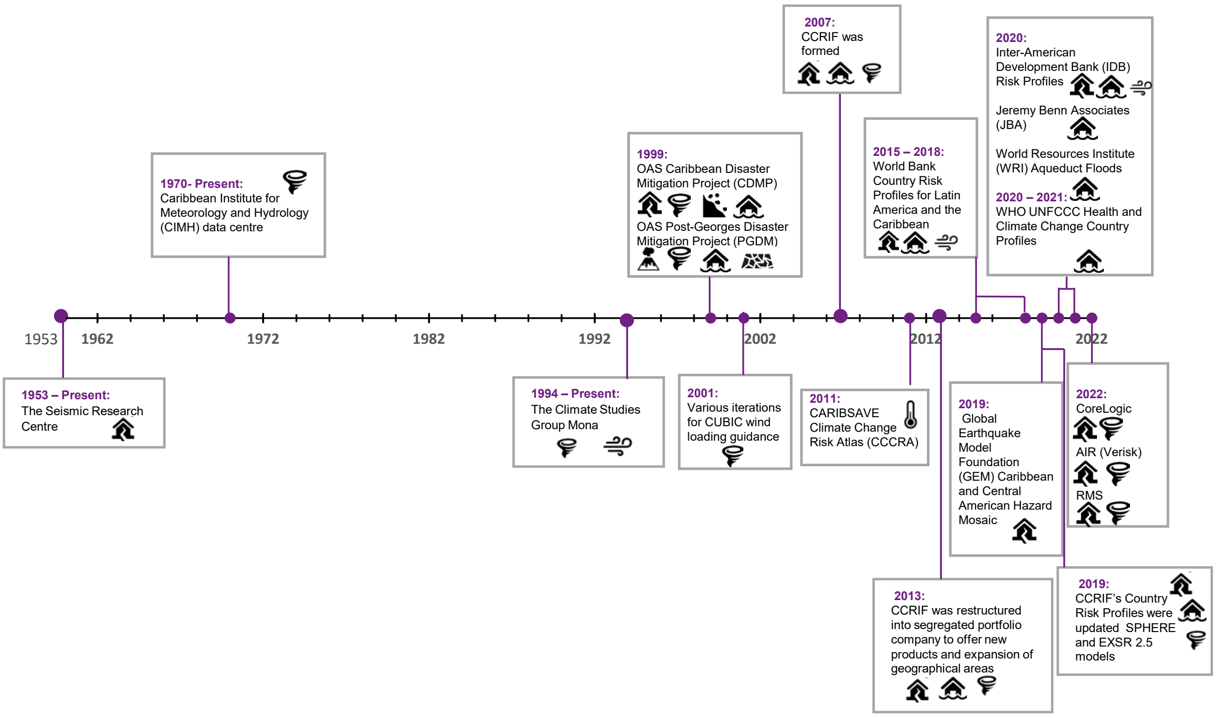


Figure 1 Timeline of hazard modelling studies conducted for the Caribbean.

Various hazard and risk profiles have been prepared for countries across the Caribbean to determine those with the greatest loss / damage potential, and to help countries prioritise disaster risk management and financing efforts. These profiles are based on a range of qualitative to quantitative approaches, include some or all of the three components of risk (i.e., hazard, exposure, vulnerability), and use both historical and model-based data and information.

Early work across in the region was undertaken by the USAID-supported, Organisation of American States (OAS)-implemented Caribbean Disaster Mitigation Project (CDMP)[12] along with successor projects. More recent examples include profiles developed and/or compiled by the Inter-American Development Bank[13], CCRIF SPC (formerly the Caribbean Catastrophe Risk Insurance Facility, CCRIF)[14], USAID[15], and the World Bank.[16] Details of these studies and compilations are provided in Section 6.1.

The Global Assessment Report on Disaster Risk Reduction (GAR15) datasets represent the most consistent approach to quantifying disaster risk across all BMC of the CDB.[17] This study developed a consistent exposure dataset (the Global Exposure Database for GAR) which includes people and the built environment across both residential and non-residential use sectors. It also developed probabilistic hazard maps and hazard-specific vulnerability curves for earthquake shaking, tropical cyclone wind, and

[12] Caribbean Disaster Mitigation Project. Accessible at: http://www.oas.org/cdmp/
[13] InterAmerican Development Bank publications. Accessible at: https://publications.iadb.org/publications
[14] CCRIF SPC Risk Profiles. Accessible at: https://www.ccrif.org/ccrifs-country-risk-profiles
[15] USAID Climate Risk Profiles. Accessible at: https://www.climatelinks.org/
[16] World Bank Country Risk Profiles for Latin America and the Caribbean. Accessible at: https://riskviewer.worldbank.org/
[17] Global Assessment Report on Disaster Risk Reduction. Accessible at: https://www.preventionweb.net/english/hyogo/gar/2015/en/home/

flood inundation.[18] GAR15 hazard data is used for tropical cyclone wind and earthquake shaking in this analysis because it is openly accessible and covers all the BMCs.

Despite being one of the few initiatives to cover all the BMCs, the GAR15 modelling outputs and associated datasets have limitations. The intention of GAR15 to provide a globally consistent risk catalogue means that the spatial resolution of datasets is relatively coarse, making them less appropriate for sub-national risk assessment and, in some cases, especially flood inundation, national risk assessment for geographically small countries. Additionally, the level of model sophistication is in some cases lower than that of commercial model vendors and institutions which focus on a single hazard (for example, the Global Earthquake Model Foundation, GEM). Further, since GAR15 was completed, our understanding and ability to model the physical processes that lead to extreme hazard events has also advanced. These shortcomings notwithstanding, GAR15 represents a solid basis for understanding of physical hazard and risk to general populations and the built environment which is consistent across all BMCs and, at the time of writing, is also the most recent and comprehensive such dataset sitting in the public domain and easily accessible.

We note that the "best" risk modelling that is currently available is that undertaken for CCRIF in 2017-18 to inform risk profiling of its member countries, for the purpose of underwriting parametric insurance. The System for Probabilistic Hazard Evaluation and Risk Assessment (SPHERA) platform includes a built environment asset database, and is the most recent comprehensive, multi-peril modelling which uses current best practice in the risk modelling universe. While regarded as being for the regional public good, and covering all BMCs, this modelling is not openly accessible.

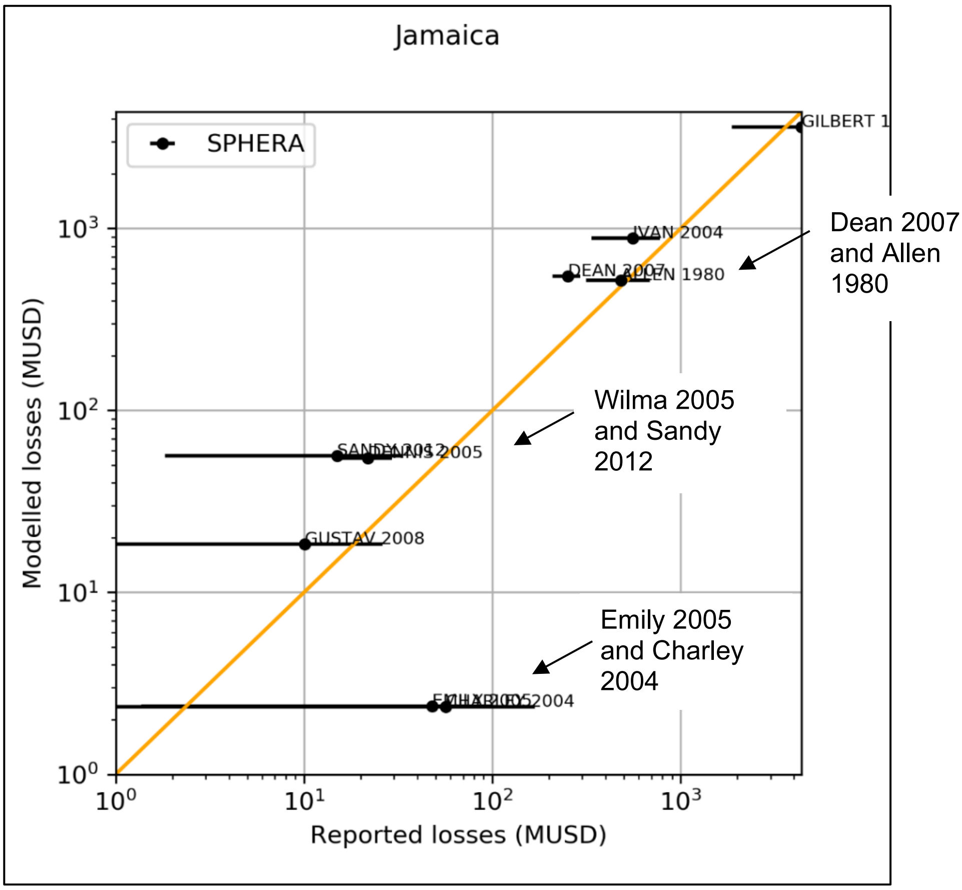
It is important to recognise that the CCRIF risk modelling has undergone several iterations since CCRIF's formation in 2007. Apart from the first iteration, each has produced hazard (earthquake and cyclone wind and surge) and exposure (for the built environment) datasets which are comprehensive and appropriate for the region, are at a resolution which is generally suitable for sub-national risk assessment, and are proven to be technically acceptable to disaster risk financing providers (see Box 1). These characteristics lead us to make a strong recommendation that efforts are made to support CCRIF, including with tangible and sustained resources. Such collaboration represents a pragmatic approach towards making risk-related datasets more readily accessible and deployable at both the national and regional levels, to underpin advances in disaster risk financing knowledge and use.

[18] Cardona et al. (2015) Background Paper: Update on the Probabilistic Modelling of Natural Risks at Global Level: Global Risk Model. Accessible at: https://www.preventionweb.net/english/hyogo/gar/2015/en/bgdocs/CIMNE_INGENIAR%20Background%20Paper%20Global%20Risk%20Model%20GAR%2015%20v1.3.pdf

Box 1: CCRIF Validation of Modelled Losses

CCRIF seeks to validate its models that underpin countries' parametric insurance policies and regularly conducts comparisons of its model outputs with actual data of on-the-ground losses. This assists the Facility in minimising basis risk associated with its products.

The graphic below shows a comparison of the modelled losses using the SPHERA model for select historical tropical cyclone events in Jamaica compared with the reported losses from a range of data sources. The graph shows the average value and the interval (minimum and maximum values) of the loss data from the reports. All monetary values are normalised to 2018.



Comparison of modelled losses with reported losses for select tropical cyclones that have affected Jamaica

The sources of data for the reported losses include: EM-DAT, NOAA, AON, Munich Re, Swiss Re, Dartmouth Flood Observatory, ReliefWeb, Wikipedia, Economic Commission for Latin America and the Caribbean, Center for Disaster Management and Risk Reduction Technology, United Nations Development Programme, International Federation of Red Cross and Red Crescent Societies, Pan American Health Organisation, Global Facility for Disaster Reduction and Recovery, International Charter: Space and Major Disasters, Local Sources (newspapers, local meteorological websites, etc.)

As the figure shows, for most of the tropical cyclone events, the modelled losses are greater than the reported losses, which means that the difference would be in the country's favor – showing that basis risk would have been small or in the country's favor.

2.3 Perception of hazard and disaster risk across the BMCs

Alongside records of historical hazard impacts and probabilistic hazard modelling, it is important to capture the perception of hazards among key stakeholders across the region, since this will impact investment and funding priorities. Risk perception may vary considerably across the BMCs, influenced by local drivers of risk, the personal (and recent) experience of individuals, and the attention that different hazards receive as part of ongoing social and political processes (e.g., election cycles). To capture hazard perception, a series of consultations were undertaken with key stakeholders drawn from across the BMCs. Three, two-hour consultations took place over the period 27 July 2022 to 05 August 2022. The consultations included a questionnaire, interactive surveys, and open discussion.

Participants were asked to indicate whether they agreed or disagreed with a series of the statements using a scale from 1 to 5 (with 5: strongly agree; 4: agree, 3: neutral, 2: disagree, 1: strongly disagree. The survey, which was completed by 33 government stakeholders, revealed that 72% of respondents strongly agreed that the costs of natural disasters were increasing, with the remaining 28% agreeing. Furthermore, 84% of respondents either strongly agreed or agreed that their country's debt-to-GDP ratio is increasing as a result of natural disasters. Jamaica was one of the few countries that disagreed with this statement, while 12% of respondents were neutral in their response.

Alongside broad agreement that the impacts of natural hazard were increasing, there was also a widespread perception that the frequency of these events had increased in the recent past. 33% of respondents strongly agreed that natural hazards impacting their country have increased in frequency over the last five years (The Bahamas, Grenada, Dominica, Barbados, Turks and Caicos Islands) with 54.5% of respondents agreeing and 12.1% neither agreeing nor disagreeing.

Figure 2 shows the results from a series of questions, asked during the consultation with the aim to elicit perspectives on disaster risk management and act as a prompt for discussion. During the consultations there was a clear awareness of the catastrophic impacts that natural hazards can have on Caribbean economies (response 1) and an appreciation that natural hazards become disasters through a combination of hazard, exposure, and vulnerability (responses 2, 3). The role of human development in driving disaster occurrence was also well understood (responses 4, 5, and 8). Stakeholders largely agreed that disasters can be prevented (response 6), and that governments should take on at least a portion of the responsibility for ensuring the development and implementation of country level disaster preparedness plans (response 7).

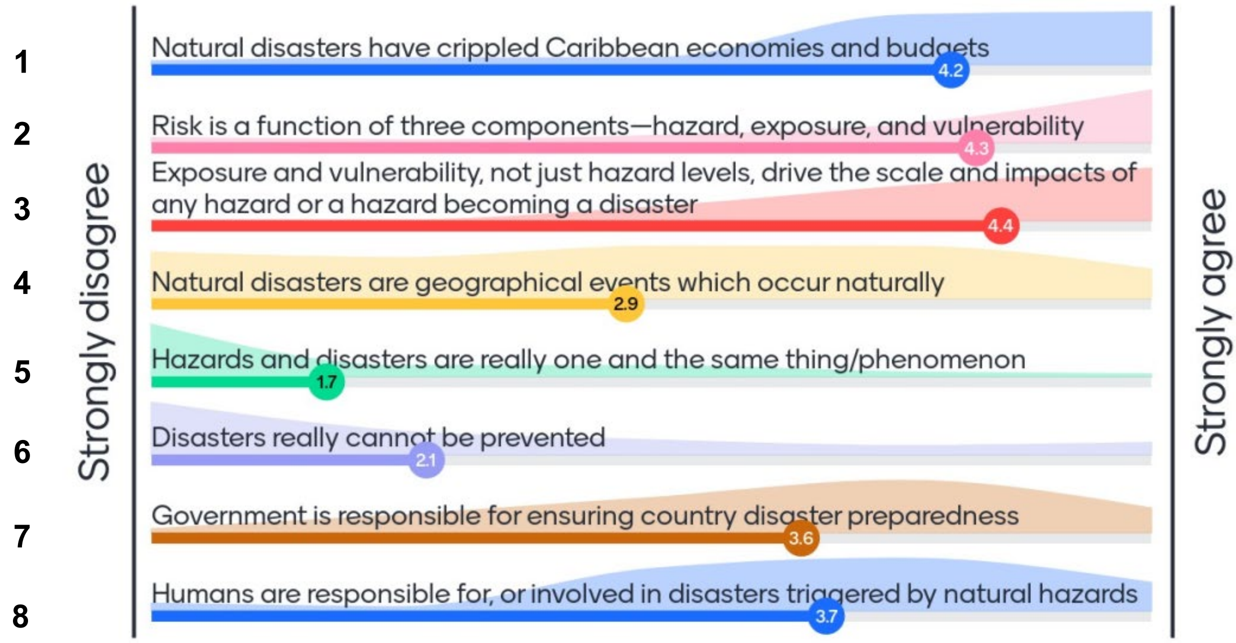


Figure 2 Risk perception among disaster risk management stakeholders across the Caribbean. Thirty-eight individuals participated in the survey over the course of three consultations.

Stakeholders were also asked to rank the hazards that they perceived *"as the most damaging / important to address"*. The results are shown in Figure 3.

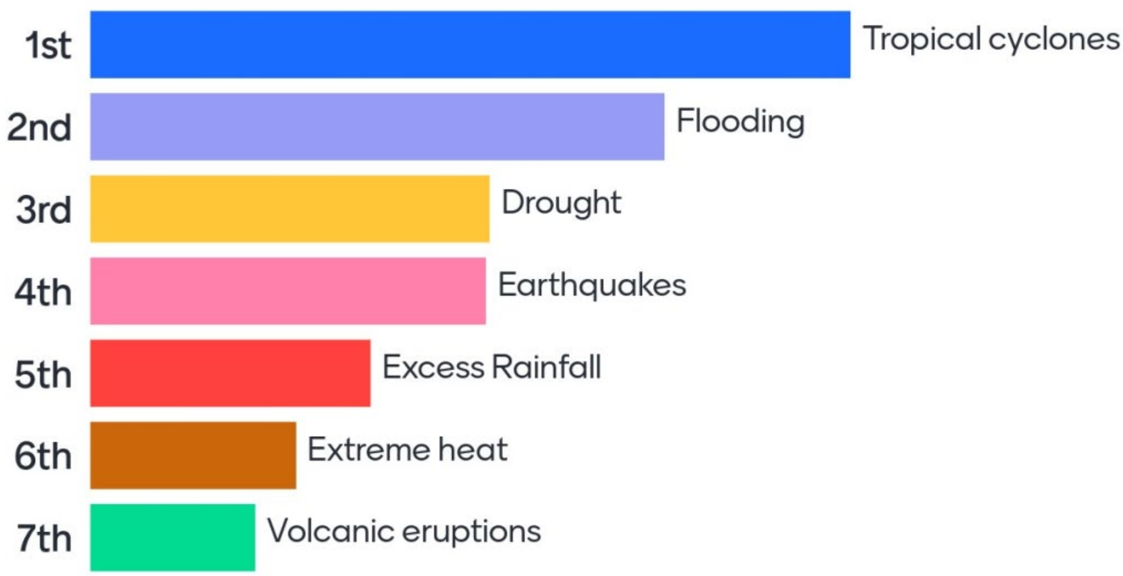


Figure 3 Perception of hazards across the Caribbean that are "the most damaging / important to address". Thirty-eight individuals participated in the survey over the course of three consultations.

Participants were shown the results of this survey during the consultation and asked to comment on them. This produced a number of insightful discussions surrounding the reasons that certain hazards are perceived as most important / damaging than others. For instance, this comment on the ranking of tropical cyclones are the predominant hazard across the region:

> *"We know we tend to pay quite a bit of attention towards these cyclones, so we have these well documented, we usually undertaken very comprehensive assessments in the aftermath of the cyclonic activity. But we also know that we have many smaller events that occur in the region, many of them are related to flood […]. A study some years ago had indicated that the most frequently occurring hazard across the CDEMA states is in fact flooding.* ***But the question is, do we have the statistics around the actual damage and losses associated with all of these smaller events****, or is it that, because we collect the information and give a lot more attention to the cyclones, that* ***we may not have a full picture of what is occurring as a result of the smaller and more cumulative events.****"*
>
> – Quote from Stakeholder Consultations

It is interesting that earthquakes appears relatively high on the above ranking, despite the reality that relatively few countries have experienced damaging earthquake impacts in the recent past. One possible explanation for this was suggested:

> "*I would also just flag that in terms of some of these risks, if you lived in Haiti then earthquakes might be higher on your list, than if you live in a country that hasn't had a devastating earthquake in recent years. [It's the] same with the volcanic eruptions, it's either you don't have a volcano, or it's been dormant, or you haven't had a significant eruption. So I* ***think a lot of those perceptions are based on what recent experience shows****, and I think the interesting thing about drought coming third is that we've seen more frequent droughts as well over the last several years in the Caribbean*"
>
> – Quote from Stakeholder Consultations

Many of the discussions centered around water extremes. There was a widespread appreciation that information (in terms of historical impacts, and ongoing monitoring) on both drought and flooding was often lacking:

> *"The* ***water related hazards are increasing in prominence in the region, and this is the water hazards at both extremes, the drought as well as the excesses in rainfall****. Specifically as relates to drought, I think traditionally in the region we do not have very robust systems that capture damage and losses from drought, and drought, as we know, impacts essentially every sector. Even in collection of information related to drought, you may see a heavier type of emphasis on the agricultural impacts, but not necessarily a dive into other sectors which are also very heavily dependent on water and the availability of water*"
>
> – Quote from Stakeholder Consultations

Despite a lack of robust historical datasets, stakeholders noted that water related hazards may interact in complex ways, with countries potentially experiencing damaging impacts from ongoing drought in parallel with extreme flooding:

> *"So there are two things we are seeing across the region, one is that yes rainfall is going to become less over time and that goes to [an earlier comment] about droughts, and* ***these droughts are to become more frequent, and more extreme. But at the same time you are going to be having these extreme rainfall events,*** *because the air is warmer, it holds more moisture, and that is why we are already starting to see an incredible amount of rainfall falling in a very short period of time. So you know, the issue with the* ***rainfall and the flooding, these tend to be discrete events that have a relatively clear start, and you know, it ends.*** *On the other side, you have droughts, and* ***droughts can be slow-onset, and cumulative, and over a longer period of time.*** *And both of these are happening in parallel, in fact it is quite common for a country to be experiencing a multi-year drought, and within that multi-year drought will suffer extreme rainfall events leading to flooding that does not get rid of the [drought]."*
>
> – Quote from Stakeholder Consultations

Finally, one participant noted the need to couple risk perception with quantitative risk assessment:

> *"There is a need to step further than just the perception and to really try to strengthen the robust body of evidence around particularly the smaller events*"
>
> – Quote from Stakeholder Consultations

The remainder of this report brings together information on hazard, exposure, and vulnerability to assess risk from key hazards across the region.

2.4 Quantifying hazard across the BMCs

2.4.1 Methodology

This review of probabilistic hazard modelling studies identifies the most appropriate hazard datasets across the BMCs. Datasets were selected based on vintage, geographical coverage, robustness of the underlying methodology, and availability (Table 3). The selected hazard datasets were deemed appropriate for the scale and ultimate application required for this study.

Hazard	Parameter	Unit	Spatial Resolution	Return Periods	Source	Use
Tropical cyclone	**Maximum Wind Speed**	Kilometers per hour (3-second gust)	~10 km	50; 100; 250; 500; 1,000	GAR15	Hazard curve derivation
Tropical cyclone	**Maximum Wind Speed**	*m/s (1-min sustained)*	*~1 km*	*20; 50; 100; 250; 500*	CCRIF	Validation
Earthquake	**Ground shaking**	Peak ground acceleration	~30 km	250; 475; 975; 1,500; 2,475	GAR15	Hazard curve derivation
Earthquake	**Ground shaking**	*Peak ground acceleration*	*~1 km*	*50; 100; 250; 500*	CCRIF	Validation
Flood (riverine)	**Inundation depth**	Meters	~1 km	2; 5; 10; 25; 50; 100; 250; 500; 1,000	WRI	Trial
Flood (coastal)	**Inundation depth**	Meters	~1 km	2; 5; 50; 100; 250; 500; 1,000	WRI	Trial
Flood	**Rainfall rate**	*mm per day*	*~10 km*	*5; 10; 25; 50*	CCRIF	Validation

Table 3 Selected probabilistic hazard datasets. Items in italics are provisional. *Sources: GAR15; World Resources Institute (WRI) Aqueduct Flood Methodology; CCRIF Risk Profiles.*

Figures 4 and 5 show regional probabilistic hazard maps at four return periods for tropical cyclone wind and earthquake shaking respectively from GAR15. Figures 6 and 7 show probabilistic hazard maps at four return periods for riverine flood and coastal flood respectively from WRI.

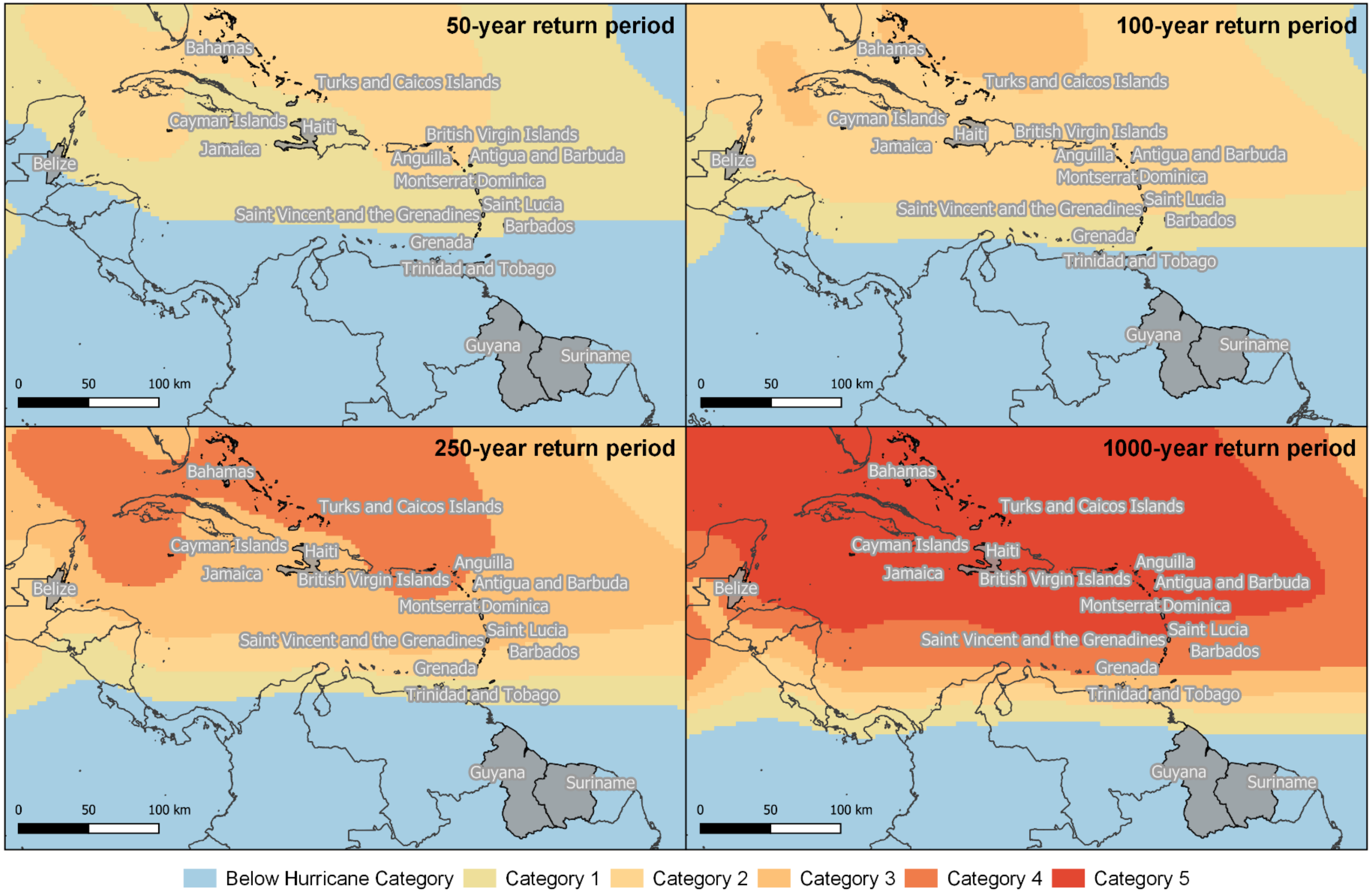


Figure 4 Tropical cyclone wind speed hazard at selected return periods. Top left: 50-year, top right: 100-year, bottom left: 250-year, bottom-right, 1,000-year. Hurricane categories are according to Saffir-Simpson Hurricane Wind Scale.

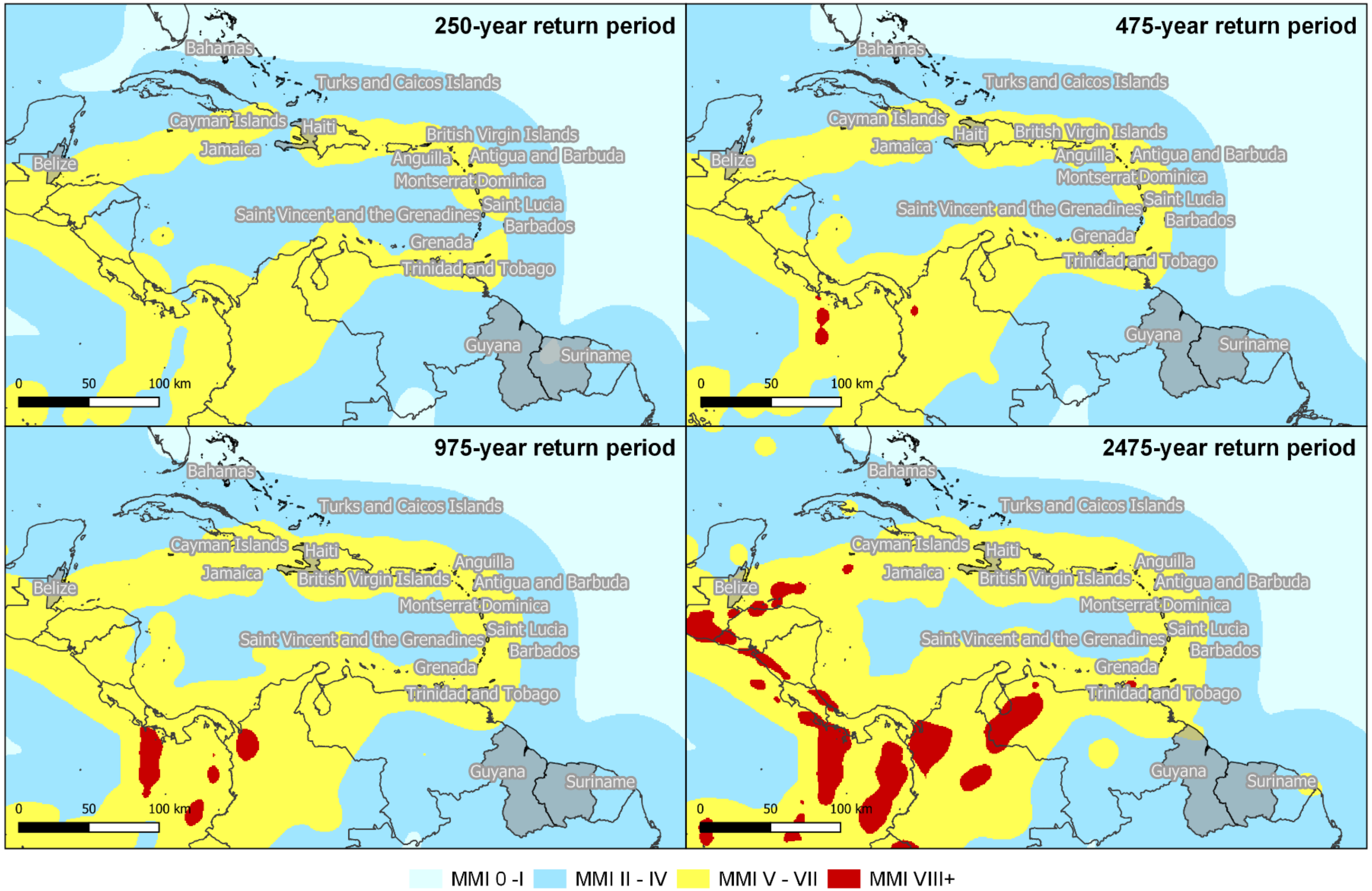


Figure 5 Earthquake shaking hazard at selected return periods. Top left: 250-year, top right: 475-year, bottom left: 975-year, bottom-right, 2,475-year. Shaking intensity is classified according to the Modified Mercalli Intensity (MMI) scale.

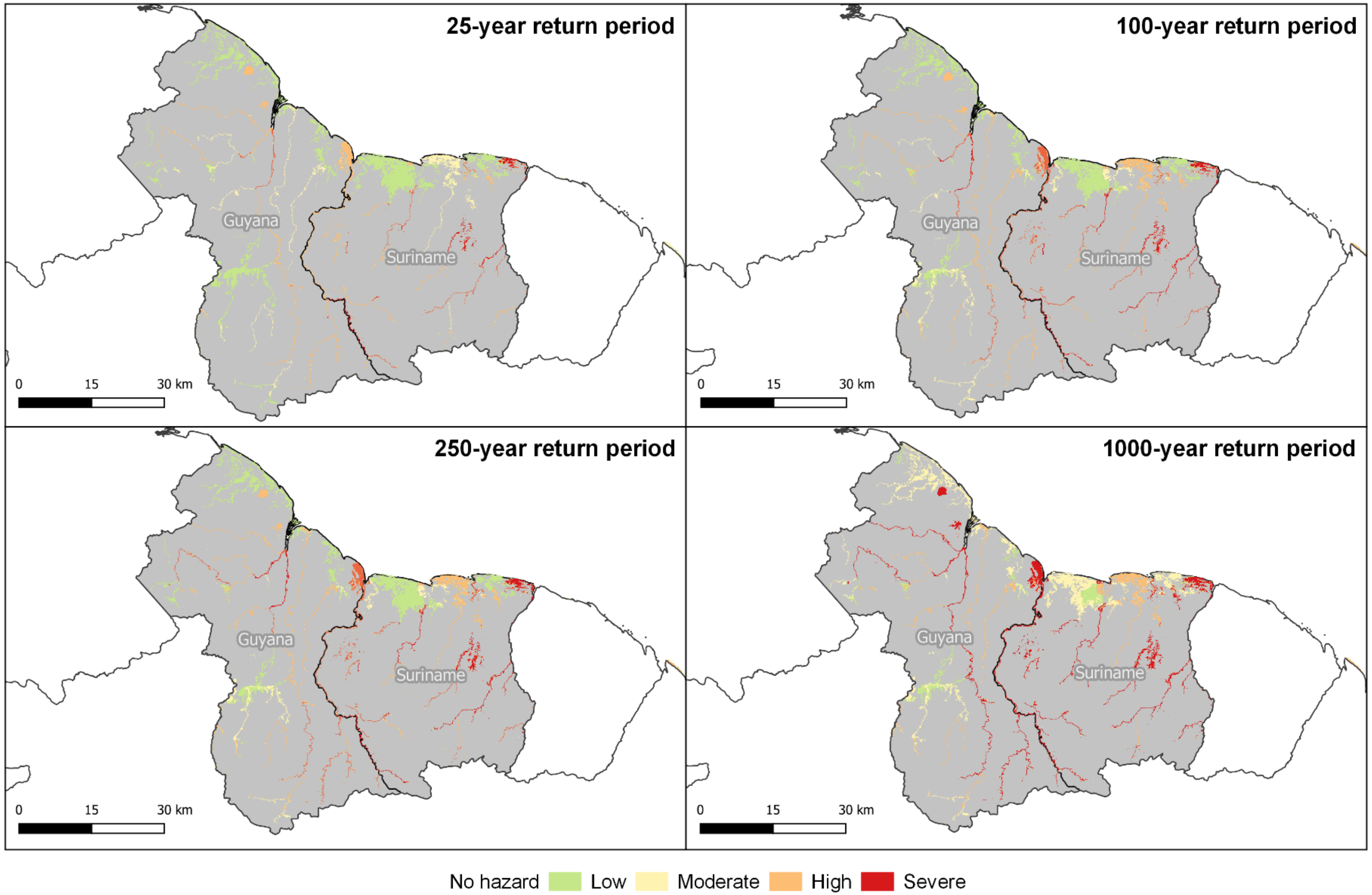


Figure 6 Riverine flood inundation hazard at selected return periods. Top left: 25-year, top right: 100-year, bottom left: 250-year, bottom-right, 1,000-year.

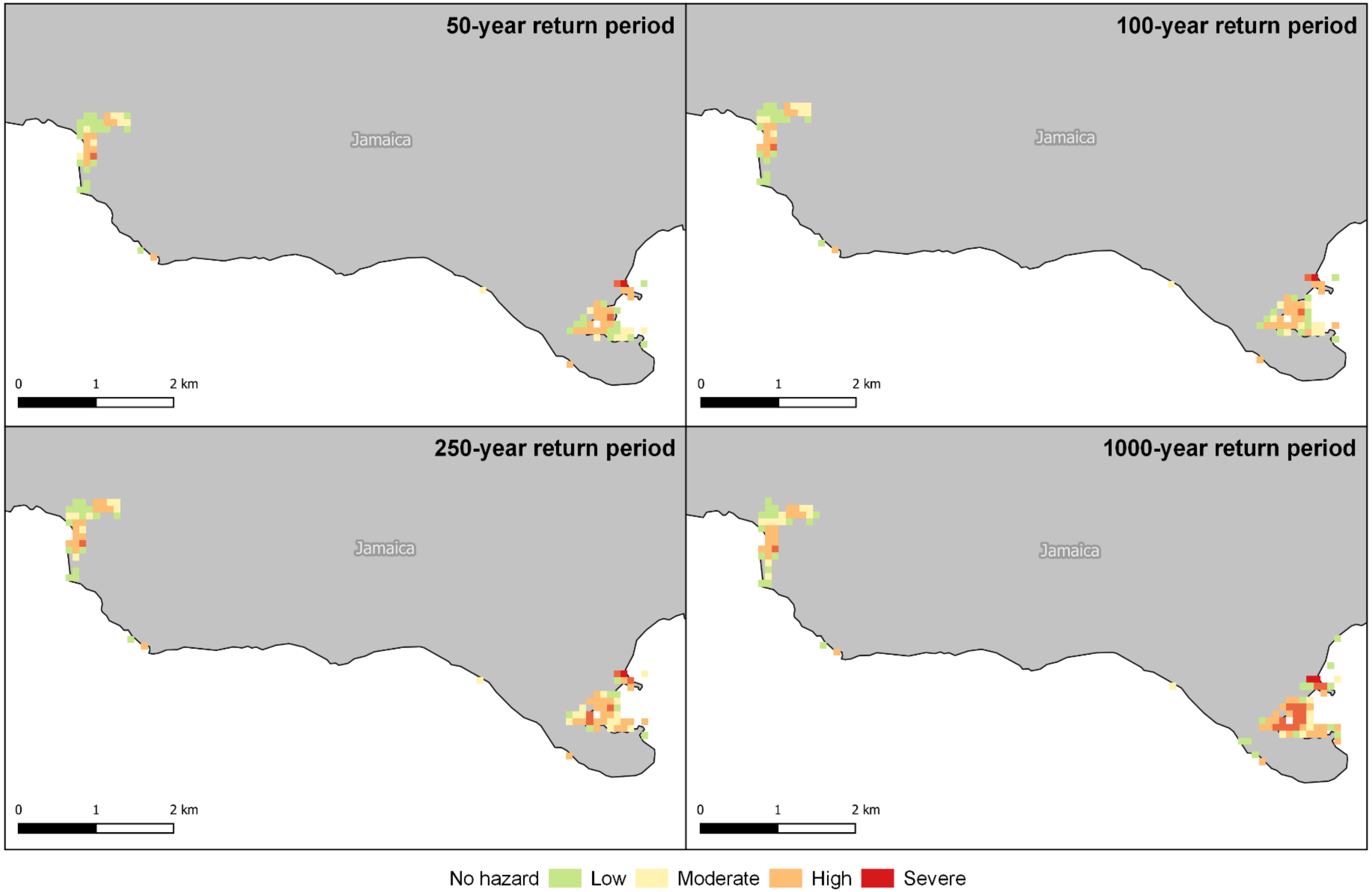


Figure 7 Coastal flood inundation hazard at selected return periods. Top left: 25-year, top right: 100-year, bottom left: 250-year, bottom-right, 1,000-year.

For each BMC, hazard intensity curves were derived based on the percentage of the population exposed to a range of hazard intensities based on classifications that are used routinely throughout the disaster risk management space, for each return period. This approach is more sophisticated than looking at hazard intensity in isolation since it considers the distribution of the population with respect to the hazard. Consequently, the outputs from this analysis can be used to identify countries where high and severe hazard intensity intersects with high population exposure. This analysis was undertaken for tropical cyclone wind and earthquake shaking. Through discussions with the CDB team, and comparison to national-scale flood modelling work, the probabilistic flood hazard maps were deemed to be of too coarse resolution to undertake meaningful quantitative analysis.

Hazard intensity thresholds were determined for tropical cyclone wind and earthquake shaking hazard (Table 4). The Saffir-Simpson scale (typically reported as 1-minute sustained wind speed) was used to inform Tropical Cyclone wind hazard thresholds. Saffir-Simpson scale thresholds were converted to 3-second gusts, following World Meteorological Organisation guidelines[19], to ensure consistency with the GAR15 hazard data layer. Wind speeds of hurricane category 1 and 2 are classified as high hazard, and wind speeds of category 3 and above as severe hazard, in accordance with the National Hurricane Center.[20]

The Modified Mercalli Intensity (MMI) scale was used as a basis for determining earthquake hazard thresholds. The MMI scale was used because it is based on the shaking experienced on the ground and includes standardised damage descriptions. The GAR15 earthquake hazard layers were converted from Peak Ground Acceleration to MMI units using the formula developed by Worden et al. (2012).[21]

[19] World Meteorological Organization (2010) Guidelines for converting between various wind averaging periods in tropical cyclone conditions. Accessible at: https://library.wmo.int/doc_num.php?explnum_id=290
[20] National Hurricane Centre. Hurricane Wind Scale. Accessible at: https://www.nhc.noaa.gov/aboutsshws.php
[21] Worden, C.B, Gerstenberger, M.C, Rhoades, D.A., and Wald, D. J. (2012) Probabilistic Relationships between Ground-Motion Parameters and Modified Mercalli Intensity in California, Bulletin of the Seismological Society of America, 102(1).

	Intensity Level	Threshold (>=)	Description
Tropical Cyclone Wind (km/h, 3-sec gust)	Tropical Depression	0.00	Low hazard
	Tropical Storm	69.93	Moderate hazard
	HU Cat 1	132.09	High hazard
	HU Cat 2	170.94	
	HU Cat 3	197.58	Severe hazard
	HU Cat 4	231.99	
	HU Cat 5	279.72	
Earthquake shaking (Modified Mercalli Intensity, MMI)	0	0.00	Low hazard
	I	1.00	
	II	2.00	Moderate hazard
	III	3.00	
	IV	4.00	
	V	5.00	High hazard
	VI	6.00	
	VII	7.00	
	VIII	8.00	Severe hazard
	IX	9.00	
	X	10.00	

Table 4 Hazard intensity thresholds for hurricane wind, and earthquake shaking.

Population distributions for each BMC were obtained from the WorldPop dataset.[22] The units of the WorldPop dataset are estimated total number of people per grid cell, with grid cells being approximately 100 m^2 at the equator. Country totals are adjusted to match the corresponding official United Nations population estimate (Table 5).

[22] WorldPop Population Counts. Constrained Individual Countries 2020 UN Adjusted. Accessible at: https://www.worldpop.org/geodata/listing?id=79

Country	Total Population
Anguilla	15,002
Antigua and Barbuda	97,928
Barbados	287,371
Belize	397,621
British Virgin Islands	30,237
Cayman Islands	65,720
Dominica	71,991
Grenada	112,519
Guyana	771,320
Haiti	11,151,060
Jamaica	2,961,161
Montserrat	4,211
Saint Kitts and Nevis	53,192
Saint Lucia	183,629
Saint Vincent and the Grenadines	110,947
Suriname	585,975
The Bahamas	393,248
Trinidad and Tobago	1,399,491
Turks and Caicos Islands	38,718

Table 5 Total population count per Borrowing Member Country, according to WorldPop 2020 UN Adjusted dataset.

To determine the intersection between hazard and population, the population dataset was converted to a point dataset and the hazard values for each return period map were added to the population points. The result is a spatial dataset that shows the total population per country that is exposed to each hazard "bucket" for each return period. This can be used to understand the relative hazard across the BMCs.

2.4.2 Results

Tropical Cyclone Wind

Figure 8 and Figure 9 show the percentage of each BMC population that is exposed to tropical cyclone winds at the 1:50-, 1:100-, and 1:250-year return periods respectively. Generally, Caribbean states in the Caribbean Sea and to the northeast of the Caribbean Sea experience the highest wind speeds for any given return period, followed by the southern ("Windward") Eastern Caribbean states (plus Jamaica and Belize), with the southern island and continental states experiencing the lowest wind hazard.

Countries can be broadly grouped based on the hazard faced. Anguilla, Antigua and Barbuda, the British Virgin Islands, the Cayman Islands, Montserrat, Saint Kitts and Nevis, The Bahamas, and the Turks and Caicos Islands are predominantly exposed to category 2 winds at 1:50-year, rising to category 4 at the 1:250-year return period.

The next group comprising, Barbados, Dominica, Haiti, Jamaica, Saint Lucia, and Saint Vincent and the Grenadines, experience wind speeds one category lower at each return period compared to the highest hazard group.

Belize, followed by Grenada and then Trinidad and Tobago face successively lower hazard relative to more northerly and north-westerly BMCs; however, the increase in hazard at higher return periods is more pronounced – for example, in Belize the majority of the population is not exposed to hurricane wind speeds at 1:50-year return period but at 1:250-year return period the majority are exposed to severe (category 3) wind speeds.

Finally, Guyana and Suriname are characterised by negligible cyclone wind hazard, thanks to their location close to the equator, where the formation of cyclonic storm systems is prevented by the very weak Coriolis effect in such geographies.

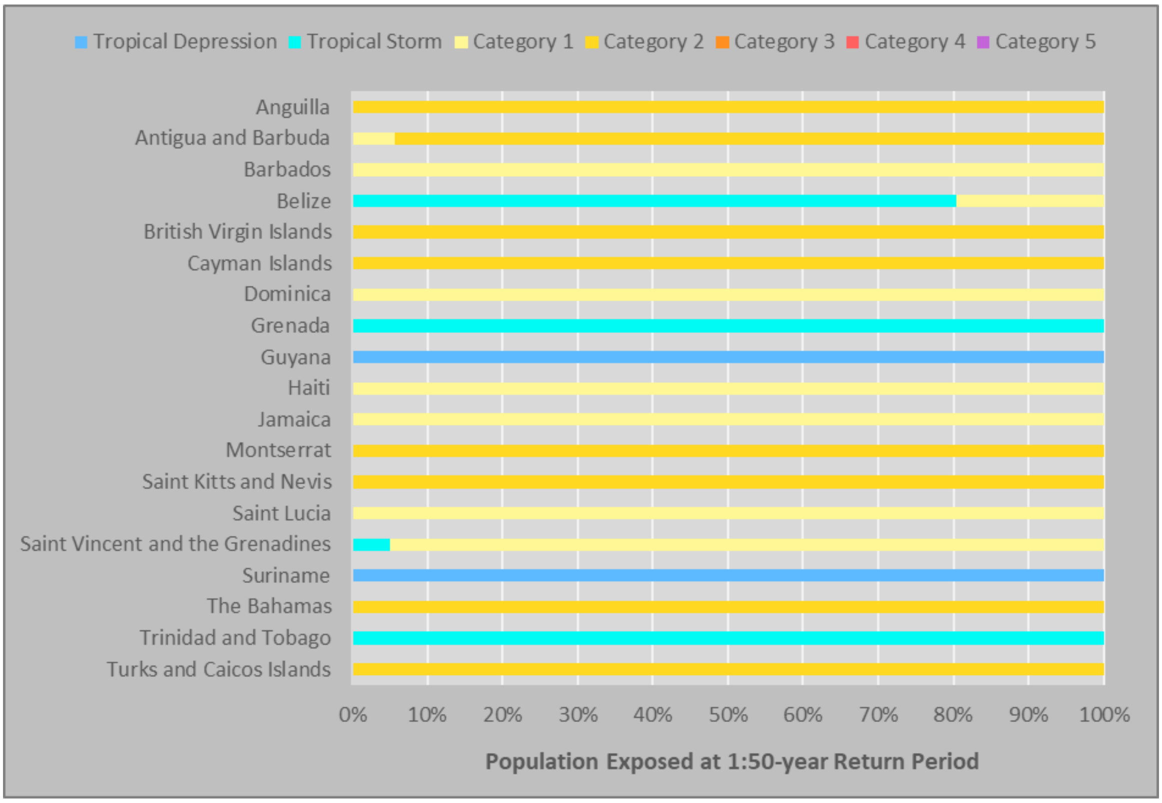


Figure 8 BMC population exposed to tropical cyclone winds at 1:50-year return period.

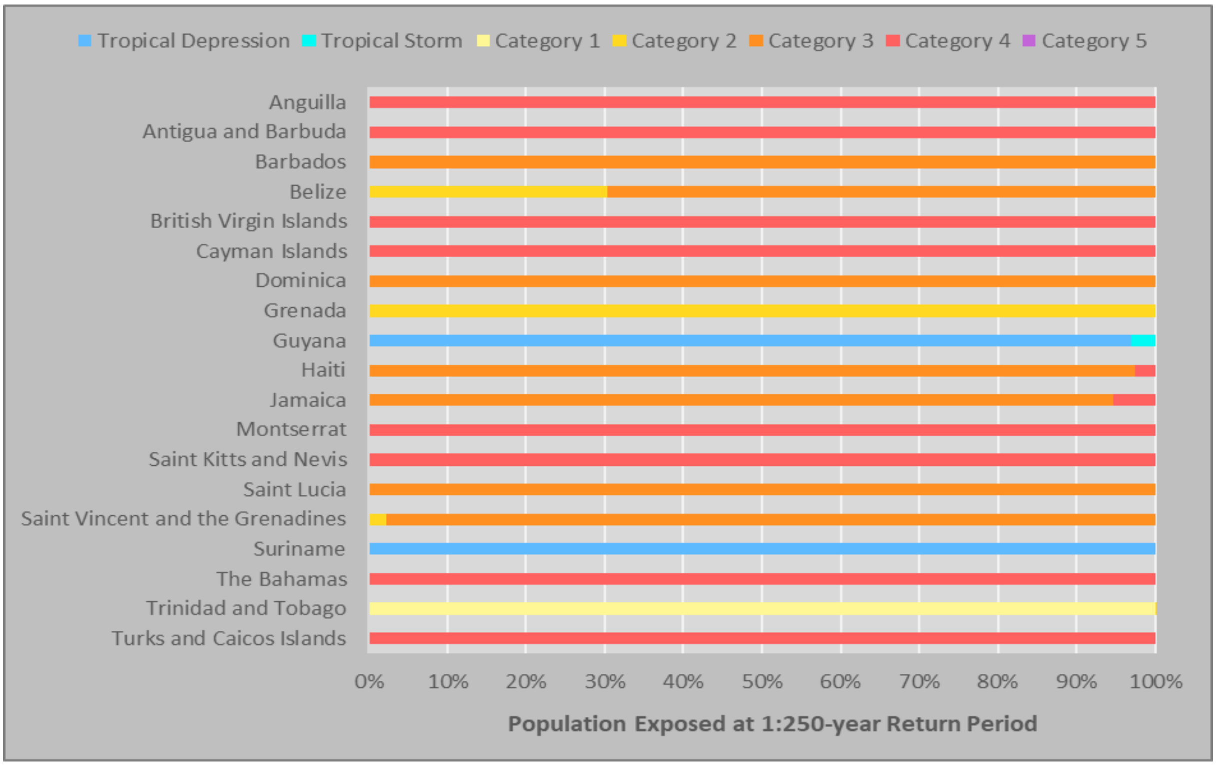


Figure 9 BMC population exposed to tropical cyclone winds at 1:250-year return period.

The above results were compared to the System for Probabilistic Hazard Evaluation and Risk Assessment (SPHERA) analysis which was completed to inform the CCRIF risk profiles. This modelling is considered to be the best available for the region, but is not publicly available. The SPHERA tropical cyclone hazard module includes a probabilistic mode which generates stochastic storm tracks and relevant parameters including wind speed and storm surge. The stochastic tracks are generated based on a statistical characterisation of historic tropical cyclone event frequency and key variables (e.g., minimum sea level pressure, maximum wind speed, radius of maximum winds) in the Central America and Caribbean region. Wind field and storm surge prediction models are used to estimate event intensities. The SPHERA model and results below take into account built infrastructure and its vulnerability to tropical cyclone hazards, so the comparison with our hazard-only analysis is not entirely like-for-like.

Countries were classified using the average annual losses modelled in SPHERA, divided by exposure (also reported in the CCRIF risk profiles). This normalisation based on exposure was undertaken to account for the substantial variation in exposed assets between countries, and to facilitate comparison with the analysis undertaken here (i.e., which also accounts for this variation by calculating the proportion of the population exposed to different hazard intensities). Countries were then ranked and grouped.

Table 6 displays reasonable agreement between the groupings based on the CCRIF modelling and that presented in this report. The slightly higher rankings of Haiti, Saint Vincent and the Grenadines, and Saint Lucia based on the CCRIF modelling can be attributed in part to their higher relative vulnerability (not accounted for in our probabilistic modelling). When historical records are also taken into account, we suggest that these three countries may be classified among the top group in terms of tropical cyclone wind hazard.

Country	AAL / Exposure	SPHERA Rank	SPHERA Grouping	WTW Grouping
Anguilla	0.276%	12	2	1
Antigua and Barbuda	0.588%	5	1	1
Barbados	0.120%	16	3	2
Belize	0.241%	13	2	3
British Virgin Islands	0.777%	4	1	1
Cayman Islands	0.327%	11	2	1
Dominica	0.334%	10	2	2
Grenada	0.184%	14	2	3
Haiti	0.514%	7	1	2
Jamaica	0.162%	15	2	2
Montserrat	1.048%	2	1	1
Saint Kitts and Nevis	0.918%	3	1	1
Saint Lucia	0.440%	8	1	2
Saint Vincent and the Grenadines	0.414%	9	1	2
The Bahamas	0.580%	6	1	1
Trinidad and Tobago	0.009%	17	3	3
Turks and Caicos Islands	1.100%	1	1	1

Table 6 Validation of tropical cyclone wind probabilistic hazard analysis.

Earthquake Shaking

Figure 10 and Figure 11, show the percentage of each BMC population that is exposed to earthquake shaking at 1:475-, 1:1,500-, and 1:2,475-year return periods respectively. The use of higher return periods for earthquake shaking reflects the frequency / severity profile of this hazard type, with earthquake events being much rarer relative to other hazards. Earthquake hazard is strongly linked to the location and character of major subduction zones. Accordingly, earthquake shaking hazard impacts countries across all of the Eastern and most of the Western Caribbean (as well as Belize). Other non-archipelagic states experience relatively lower earthquake hazards.

As with tropical cyclone wind, it is possible to identify several broad groupings of countries based on their exposure to earthquake shaking hazard. Anguilla, Antigua and Barbuda, Dominica, Jamaica, Montserrat, Saint Kitts and Nevis, and Trinidad and Tobago comprise the first group, with the majority of their population exposed to earthquake shaking equivalent to MMI VI (strong perceived shaking with potential for light damage) at the 1:475-year return period. At 1:1,500-year return period, the populations of Antigua and Barbuda, Dominica and Montserrat can expect to experience MMI VII (very strong perceived shaking with potential for moderate damage). The populations of Jamaica, Saint Kitts and

Nevis, and Trinidad and Tobago can be expected to experience this level of shaking at the 1:2,475-year return period.

The next group includes Barbados, Belize, the British Virgin Islands, the Cayman Islands, Grenada, Haiti, and Saint Lucia. At the 1:250-year return period, the populations of these countries predominantly face earthquake shaking equivalent to MMI V (moderate perceived shaking with potential for very light damage) increasing to MMI VI at higher return periods. Belize stands out as experiencing an especially diverse range of earthquake shaking intensities from IV to VII at the 1:2,475-year return period.

Guyana, Saint Vincent and the Grenadines, Suriname, and the Turks and Caicos Islands experience relatively low earthquake shaking hazard, ranging from MMI II (weak perceived shaking with little to no potential for damage) to MMI IV (light perceived shaking with little to no potential for damage). At the 1:1,500-year and 1:2,475-year return period, the hazard exposure of Saint Vincent and the Grenadines does increase markedly with some of the population exposed to an MMI VI at the higher return period.

Finally, The Bahamas experiences the lowest earthquake shaking hazard with an MMI of 0 – I at the 1:475-year return period, with only a small proportion of the population exposed to hazard of greater than MMI I even at the highest return period.

Figure 10 BMC population exposed to earthquake shaking at 1:475-year return period.

Figure 11 BMC population exposed to earthquake shaking at 1:2,475-year return period.

The above results were compared to the SPHERA analysis which was completed to inform the CCRIF risk profiles. This modelling is considered to be the best available for the region, but is not publicly available. The SPHERA earthquake hazard module provides a stochastic catalogue of potential future earthquakes derived from modelling of the frequency/severity relationships established in historical catalogues. The generation of stochastic events is based on information about location, geometry and rate of activity of the earthquake sources (faults) present in the area of interest. The SPHERA model and results below take into account built infrastructure and its vulnerability to earthquake shaking, so the comparison with our hazard only analysis is not entirely like-for-like.

Table 7 shows good agreement between the grouping based on the SPHERA modelling and that presented in this report. Haiti and Barbados are assigned a higher rank based on the SPHERA modelling, likely due to the impact of including exposure and vulnerability information. Our analysis, considering hazard alone, assigns a higher ranking to Jamaica and Saint Vincent and the Grenadines compared to the SPHERA risk modelling.

Countries were classified using the average annual losses modelled by the SPHERA approach, divided by exposure (also reported in the CCRIF risk profiles). This normalisation based on exposure was undertaken to account for the substantial variation in exposed assets between countries, and to facilitate comparison with the analysis undertaken here (i.e., which also accounts for this variation by calculated the proportion of the population exposed to different hazard intensities). Countries were then ranked and grouped.

Country	AAL / Exposure	SPHERA Rank	SPHERA Grouping	WTW Grouping
Anguilla	0.062%	3	1	1
Antigua and Barbuda	0.057%	4	1	1
Barbados	0.028%	9	1	2
Belize	0.004%	14	2	2
British Virgin Islands	0.004%	15	2	2
Cayman Islands	0.018%	10	2	2
Dominica	0.040%	6	1	1
Grenada	0.010%	13	2	2
Haiti	0.154%	1	1	2
Jamaica	0.017%	11	2	1
Montserrat	0.048%	5	1	1
Saint Kitts and Nevis	0.029%	8	1	1
Saint Lucia	0.031%	7	1	2
Saint Vincent and the Grenadines	0.017%	12	2	1
The Bahamas	0.000%	16	3	3
Trinidad and Tobago	0.108%	2	1	1
Turks and Caicos Islands	0.000%	16	3	3

Table 7 Validation of earthquake shaking probabilistic hazard analysis.

Flooding

The WRI riverine and coastal inundation datasets are the highest resolution datasets (at 1 km resolution) that are consistently available across the BMCs. Despite the regional consistency, the resolution of these probabilistic flood maps represent a key limitation. In reality, flood hazard can vary considerably (e.g., from severe flooding to minimal flooding) over a few meters to tens of meters horizontally. As a result, the WRI datasets are insufficient to adequately assess flood hazard using the same approach as described for tropical cyclone wind and earthquake shaking.

To fully understand riverine and coastal flood hazard in any given national context requires detailed hydrodynamic modelling as well as high resolution topography (and, for coastal flooding, nearshore bathymetry). Such modelling has only been undertaken in some countries and, usually, for only certain areas of these countries. Table 8 gives details of some flood hazard information that has been produced across the BMCs. The CDEMA GeoCRIS platform represents the most comprehensive source of geospatial flood information. However, in the majority of cases, although data can be viewed on the platform, it cannot be downloaded for further analysis. Furthermore, the methodology used to produce these datasets is not always provided.

Country	Description	Available in GIS format?	Source
Belize	Coastal Flood Depth for Hurricane Categories (1 to 5)	No	CDEMA GeoCRIS
Belize	Coastal Flood Hazard	No	CDEMA GeoCRIS
Belize	Fluvial and Pluvial Flood Hazard Categories	No	CDEMA GeoCRIS
Dominica	Flood Hazard Map	No	CDEMA GeoCRIS
Dominica	Flash Flood Susceptibility	Yes	CDEMA GeoCRIS
Dominica	Storm Surge Susceptibility (2006)	Yes	CDEMA GeoCRIS
Grenada	Flash Flood Extent	No	CDEMA GeoCRIS
Jamaica	Return Period Flood Extent	No	Jamaica Water Resources Authority
Saint Lucia	Coastal Hazards	Yes	CDEMA GeoCRIS
Saint Lucia	Flood Susceptibility Map	No	CDEMA GeoCRIS
Saint Vincent and the Grenadines	Flash Flood Hazard	No	CDEMA GeoCRIS
Turks and Caicos	Flood Hazard Extent	Yes	CDEMA GeoCRIS
Turks and Caicos	Hurricane Category 1 Storm Surge Hazard Extent	No	CDEMA GeoCRIS
Turks and Caicos	Tropical Storm Surge Hazard Extent	No	CDEMA GeoCRIS

Table 8 National scale, high resolution flood hazard datasets.

Figure 12 provides an example of the national scale flood hazard / risk datasets listed in Table 8. This hazard information is at much higher resolution than is typically available across the BMCs. Given that such information is not consistently available across the BMCs, we suggest that the excess rainfall modelling undertaken using the SPHERA platform is used, alongside stakeholder consultations, to assess relative flood hazard across the region. Outputs from this model are presented in the following section.

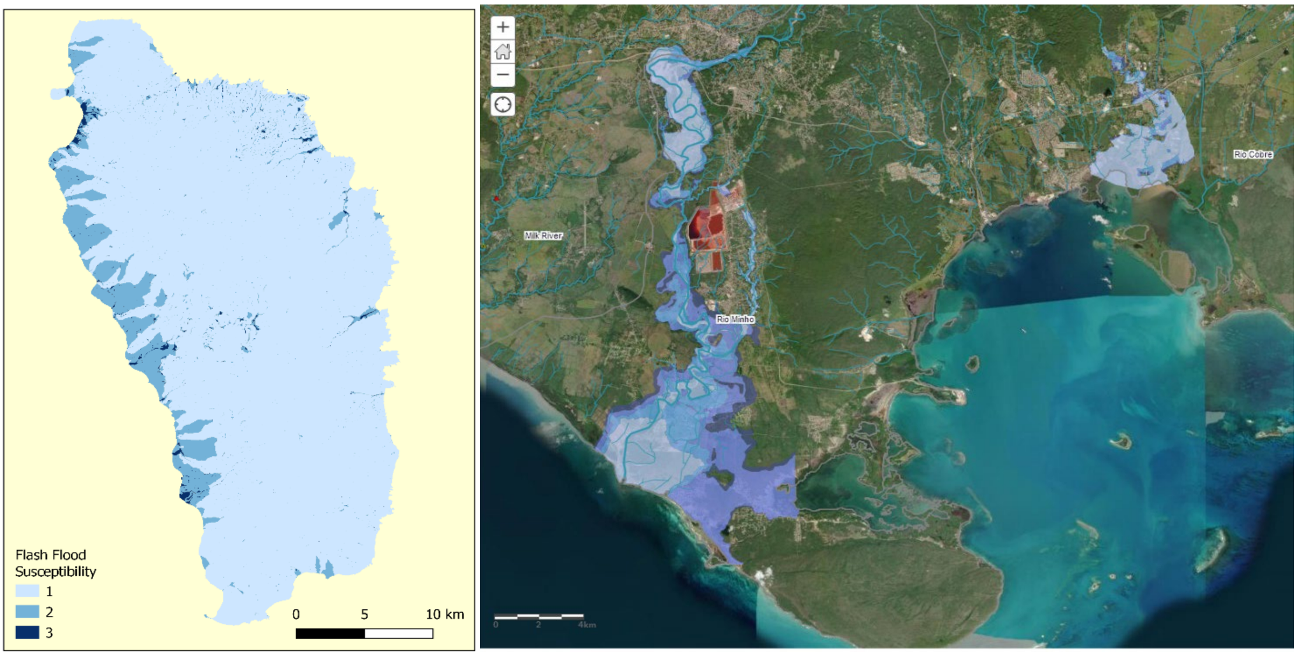


Figure 12 Examples of national scale flood risk modelling datasets. Left, flood susceptibility map for Dominica[23]; right, flood extent map for Jamaica (Jamaica Water Resources Authority)[24]

Table 9 presents the excess rainfall modelling undertaken by CCRIF in SPHERA. The SPHERA hazard module simulates excess rainfall events using a combination of climatic-meteorological models and satellite-based precipitation models. The former set of models are weather forecast models and capable of accurately reproducing the intensity of rainfall events. This is complemented by the satellite-based models which more precisely capture the spatial and temporal distribution of rainfall. As explored above, it was not possible to assess flood hazard at the regional scale due to a lack of high resolution hazard data. Accordingly, this modelling is used to inform the country groupings, alongside qualitative information from stakeholder consultations.

"*While undoubtedly tropical cyclones and strong hurricanes, and we remember 2017 quite vividly, while those issues are very present in our minds,* ***a lot of the disasters that we are seeing across the region come from flooding and come from excess rainfall events, and the damages are equivalent to more than say just from hurricanes***."

– Quote from Stakeholder Consultations

[23] https://www.arcgis.com/home/webmap/viewer.html?webmap=645025797e0947c68388adcd8c455995&extent=-78.9494,17.2273,-75.5765,18.9166
[24] https://www.arcgis.com/home/webmap/viewer.html?webmap=645025797e0947c68388adcd8c455995&extent=-78.9494,17.2273,-75.5765,18.9166

Country	AAL / Exposure	Rank	Rank Grouping
Anguilla	0.759%	6	1
Antigua and Barbuda	0.560%	10	2
Barbados	0.473%	14	2
Belize	0.999%	3	1
British Virgin Islands	0.829%	5	1
Cayman Islands	1.193%	1	1
Dominica	0.669%	8	1
Grenada	0.402%	16	2
Haiti	0.457%	15	2
Jamaica	1.142%	2	1
Montserrat	0.564%	9	2
Saint Kitts and Nevis	0.694%	7	1
Saint Lucia	0.503%	12	2
Saint Vincent and the Grenadines	0.487%	13	2
The Bahamas	0.521%	11	2
Trinidad and Tobago	0.138%	17	3
Turks and Caicos Islands	0.957%	4	1

Table 9 Excess rainfall (cyclonic and non-cyclonic) probabilistic hazard analysis.

Drought

A regional probabilistic drought model has not yet been developed for the Latin America and Caribbean region. Through a review of drought risk modelling capabilities across the region, the following elements emerge as key challenges / priorities:

- Drought modelling should take into account the varying definitions (e.g., time period, spatial extent, severity), and types (meteorological, hydrological, agricultural, socioeconomic) of drought. The nature of drought hazard will vary between countries (and within countries for particular sectors) so establishing the most "important" types of drought in any specific context is an important starting point before investing in model development;
- Any regional drought model would need to be tailored to specific country contexts. For instance, the mix of crops that are important will differ between countries, and the production of crops for subsistence / export will also vary. Different crops have different drought tolerance thresholds which will result in varied drought impacts event given common meteorological / hydrodynamic conditions; and
- The availability of data for validation varies across the region. Validation information must be identified in order to ensure that models are calibrated appropriately.

*"**We don't have a centralized database that's across all of our member states in the region**. However, I believe that a fair amount of that information exists in national jurisdictions across the region, where **the national emergency management organisations and the various ministries, of agriculture for example, may be tracking the impacts of droughts**. Every now and again we see publications issued by national governments about the damage caused by droughts and the agricultural sector, so I am sure this is something that is tracked across many jurisdictions. **There is no single location that I am aware of that captures this and tracks that and this is something that obviously would be a good thing to have.**"*

– Quote from Stakeholder Consultations

In the absence of quantitative, probabilistic drought model outputs, this section focuses on collating details of historical drought events to build up an understanding of the drivers of drought hazard, and associated impacts across the region. Table 10 summarises major drought events across the Caribbean.

Year	Countries Impacted	Hazard Description
1997 – 1998	Barbados, Dominica, Jamaica, Guyana, Trinidad and Tobago	The event started in December 1997 with weak easterly winds, cooler Caribbean basin temperatures. Associated with moderate El Niño.
2009 – 10	Antigua and Barbuda, Bahamas, Barbados, Bermuda, Dominica, Jamaica, Guyana, Grenada, Saint Lucia, Saint Vincent and Grenadines, Trinidad and Tobago	The event started in October 2009 (normally the wet season) in the south-eastern Caribbean and spread upwards. Below average rainfall continued until April/May 2010. Between March 2009 and February 2010 rainfall was less than 50% of the average, with February 2010 in particular experiencing 0.03% of the monthly average. Impacts on rainfall were mirrored across the majority of the Caribbean to varying degrees, in particular the eastern Caribbean, where rainfall was in the lowest 10% (some as record lows) of recorded totals for February.[25] Associated with strong El Niño.
2013 – 16	Antigua & Barbuda, Barbados, Belize, British Virgin Islands, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, and Trinidad and Tobago	Associated with strong El Niño. The duration, severity, and spatial extent of this event sets it apart from the 1997-98 and 2009-10 droughts. This event impacted 80% of the Caribbean and Central America. Studies suggest that anthropogenic activity contributed to the severity of this event.[26]

[25] https://drought.unl.edu/archive/Plans/Drought/International/FAO_Carib_Report.pdf
[26] Herrera, D., J. T. Fasullo, S. J. Coats, C. M. Carrillo, B. I. Cook, and A. P. Williams, 2018: Exacerbation of the 2013–2016 Pan-Caribbean drought by anthropogenic warming. Geophys. Res. Lett., 45, 10 619–10 626, https://doi.org/10.1029/2018gl079408

Year	Countries Impacted	Hazard Description
2019 – 20	Bahamas, Barbados, Belize, Cayman Islands, Haiti, Trinidad and Tobago, Saint Lucia, Saint Vincent and Grenadines	Associated with moderate El Niño. The November/December 2019 rainy season was delayed with low rainfall and high temperatures leading to recurrent heatwaves across the region.[27] Resulted in highest maximum (Guyana, Haiti) and lowest minimum (Guyana, Dominica) temperatures being recorded at weather stations.

Table 10 Major drought events across the Caribbean.

In general, the Caribbean archipelagic states experience distinct wet and dry seasons with the wet season beginning in May to June, and continuing until October before transitioning to a dry season in November / December. On average, 70 – 80% of rainfall occurs during the wet season.[28] During the wet season, the Caribbean and Central America typically experience a period of reduced rainfall known as the "midsummer drought". This period of reduced rainfall tends to begin in July / August, before being replaced by the peak of rainy season in September / October.[29] Belize, Guyana, and Suriname are similarly impacted by a wet and dry season, dictated largely by the seasonal shifts of the Inter Tropical Convergence Zone (ITCZ). Drought events occur as a result of disruption to these seasonal rainfall patterns. In the past, dry conditions during one season have been offset by a following wetter period meaning that impacts tend to be seasonal, rather than extending over 3+ years.[30]

> *"As we know, **CARICOM has about 8 of the top 10 water scarce countries**, so droughts just exacerbate the issue of water security which then expands to other areas like food security and so on."*
>
> – Quote from Stakeholder Consultations

The occurrence and severity of drought events across the Caribbean is strongly correlated with the El Niño phase of the ENSO phenomenon. This happens because of the persistence of stable, high pressure conditions over the Caribbean basin, weaker easterly winds (which deliver less moisture from the tropical North Atlantic), and cooler Caribbean basin temperatures, during the El Niño phase. The major drought events listed in Table 10 clearly coincide with strong El Niño conditions shown in Figure 13. Droughts have occurred across the region during periods not associated with El Niño conditions suggesting that drought variability may be influenced by other forcing factors.

[27] https://reliefweb.int/sites/reliefweb.int/files/resources/1272_Statement_LAC_en_big.pdf
[28] Farrel, D., Trotman, A., and Cox, C. Drought early warning and risk reduction: a case study of the Caribbean drought of 2009 – 2010.
[29] Herrera, Dimitris & Ault, Toby & Carrillo, Carlos & Li, Xiaolu & Fasullo, John & Evans, Colin & Alessi, Marc & Mahowald, Natalie. (2020). Dynamical Characteristics of Drought in the Caribbean from Observations and Simulations. Journal of Climate. 33. 10773–10797. 10.1175/JCLI-D-20-0100.1.
[30] https://drought.unl.edu/archive/Plans/Drought/International/FAO_Carib_Report.pdf

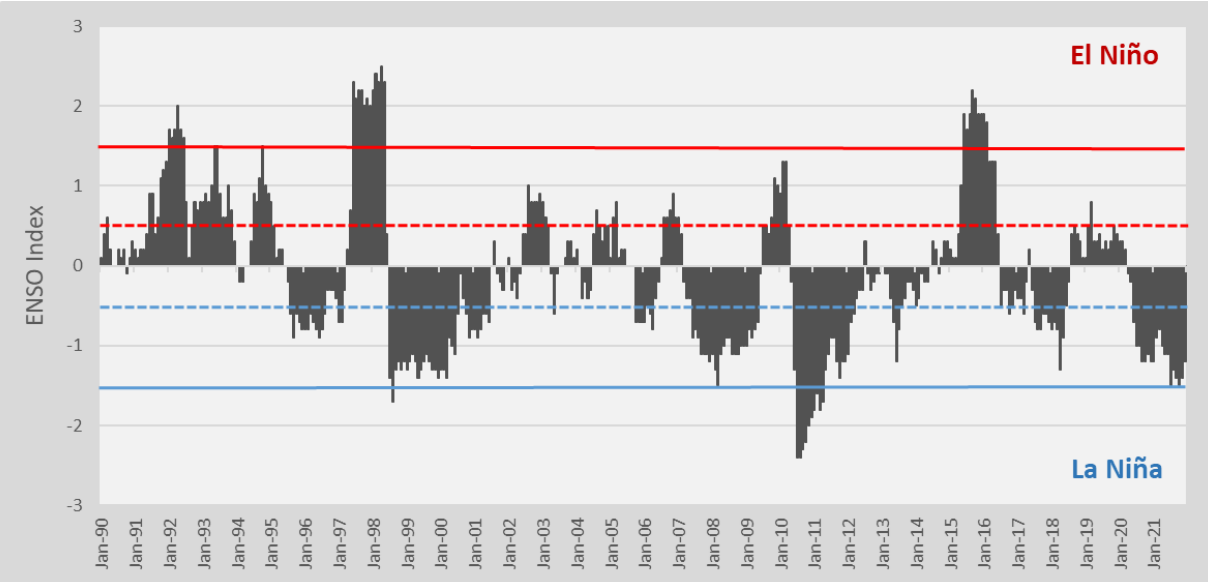


Figure 13 El Niño – Southern Oscillation (ENSO) Index, 1990 – 2021. An ENSO Index greater than +0.5 indicates El Niño conditions while an ENSO Index less than -0.5 indicates La Niña conditions.

The 1997-98 drought resulted in reduced crop yields and resultant food price increases across impacted countries of around 20%. Barbados suffered localised water shortages with knock-on impacts across the agricultural sector including increased reliance on crop imports. Numerous countries experienced reduced crop production in key export crops, for example, Dominica (bananas), Jamaica (sugar cane), and Guyana (rice and sugar).[31] In Guyana, this drought is remembered as the most severe in history, resulting in severe water stress that impacted 80% of the population.[32]

"*To me there's those two sides, I live in Barbados, a water-scarce country, and you see it when there's a drought, you have restrictions on the amount of water that can be used, you read in the news about the level of the reservoirs, but you don't hear as much about farmers, and people dependent on agriculture and how that impacts them.*"

– Quote from Stakeholder Consultations

The 2009-10 drought caused extensive crop yield reductions, lost economic output from key sectors, and increased incidence of bush fires.[33] Reductions in crop yields from the 2009-10 drought resulted in food price increases of over 30%, and in some countries over 60% (Trinidad and Tobago). Guyana rice and sugar industries were badly impacted due to limited water supply for irrigation.[34] Similar losses to agricultural production were also experienced in Antigua and Barbuda (tomatoes and onions), Dominica (bananas), Grenada (bananas, root crops), Saint Kitts and Nevis (water melon, cucumber, lettuce), Saint Lucia (coconuts, cashews, oranges), Saint Vincent and the Grenadines (rice, tomatoes), Trinidad and Tobago (fruits). In Barbados, water rationing was introduced as aquifers lowered to critical levels, while

[31] https://drought.unl.edu/archive/Plans/Drought/International/FAO_Carib_Report.pdf
[32] https://drought.unl.edu/archive/Documents/NDMC/Workshops/13/Pres/Seulall.pdf
[33] https://drought.unl.edu/archive/Plans/Drought/International/FAO_Carib_Report.pdf
[34] https://drought.unl.edu/archive/Documents/NDMC/Workshops/13/Pres/Seulall.pdf

in Jamaica and Grenada water had to be imported / redistributed across the country. Other countries suffering severe water shortages include Saint Lucia, Saint Vincent and the Grenadines, and Trinidad and Tobago. Grenada suffered damaging bushfires which destroyed nutmeg, cocoa and citrus crops, and required the diversion of domestic water supplies for firefighting. Further bushfires were reported across Barbados, Dominica, Jamaica, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago.

Known as the "Pan-Caribbean drought" of 2013-16, it is estimated that >3 million people were directly impacted by food insecurity because of the failure of staple crops.[35] Water shortages were reported as significantly impacting the tourism industry in Anguilla, Antigua and Barbuda, Barbados, British Virgin Islands, Saint Kitts and Nevis, and Trinidad and Tobago. Antigua and Barbuda declared a water emergency as depletion of surface water sources necessitated a 90% resilience on seawater desalination. Reduced water levels in reservoirs and other surface water sources was also reported in Barbados, Grenada, Haiti, Jamaica, Saint Kitts and Nevis, Saint Vincent and the Grenadines, and Trinidad and Tobago. In Haiti, food shortages and price inflation precipitated a widespread humanitarian crisis in which an estimated 76,000 children suffered from acute malnutrition, with severe food insecurity extending to 3.6 million people.[36] Increased incidence of bushfires was reported in Barbados, Jamaica, Saint Vincent and the Grenadines, and Trinidad and Tobago.

"*My impression over the last few years is that* ***drought is very much treated differently from some of these other hazards.*** *It is interesting [hearing the discussion] about the water scarcity issue, and I think that is where it resonates a little bit more with governments, but when you see droughts in more agrarian countries, it doesn't necessarily trigger the same types of responses as a sudden onset emergency would trigger. You know, there's no CCRIF policy, at the macro level at least, that's designed for drought. So* ***countries aren't necessarily thinking about contingency funds for those slow onset disasters.*** *So I think the other challenge is thinking about, at what point does that trigger being an emergency to households that are impacted.* ***So I think that when you see the destruction that a hurricane or an earthquake can wreak on a country, it's a lot more tangible, and I think with droughts it can just be a little bit more challenging, those slow-onset types of emergencies****."*

– Quote from Stakeholder Consultations

The Caribbean Institute for Meteorology and Hydrology (CIMH) is the key center for expertise on drought understanding and monitoring, for instance through the Caribbean Drought and Precipitation Monitoring Network (CDPMN) which was launched in 2009.[37] The CDPMN monitors drought at the regional and national scales and reports on monthly rainfall and temperature, along with common indicators of drought including the Standardised Precipitation Index (SPI), and Standardised Precipitation Evapotranspiration Index (SPEI). These reports make use of station-based observations and NCEP/NCAR reanalysis data to calculate indices on a 1, 3, 6, and 12 month time interval. SPI maps for each are accompanied by a description of current conditions.[38] While the initial focus of the CDPMN has been on meteorological drought, the intention is to extend this to also consider hydrological and agricultural drought in future.

[35] Herrera, Dimitris & Ault, Toby & Carrillo, Carlos & Li, Xiaolu & Fasullo, John & Evans, Colin & Alessi, Marc & Mahowald, Natalie. (2020). Dynamical Characteristics of Drought in the Caribbean from Observations and Simulations. Journal of Climate. 33. 10773–10797. 10.1175/JCLI-D-20-0100.1.
[36] https://reliefweb.int/disaster/dr-2015-000091-hti
[37] https://rcc.cimh.edu.bb/climate-monitoring/caribbean-drought-and-precipitation-monitoring-network/
[38] https://rcc.cimh.edu.bb/spi-monitor/

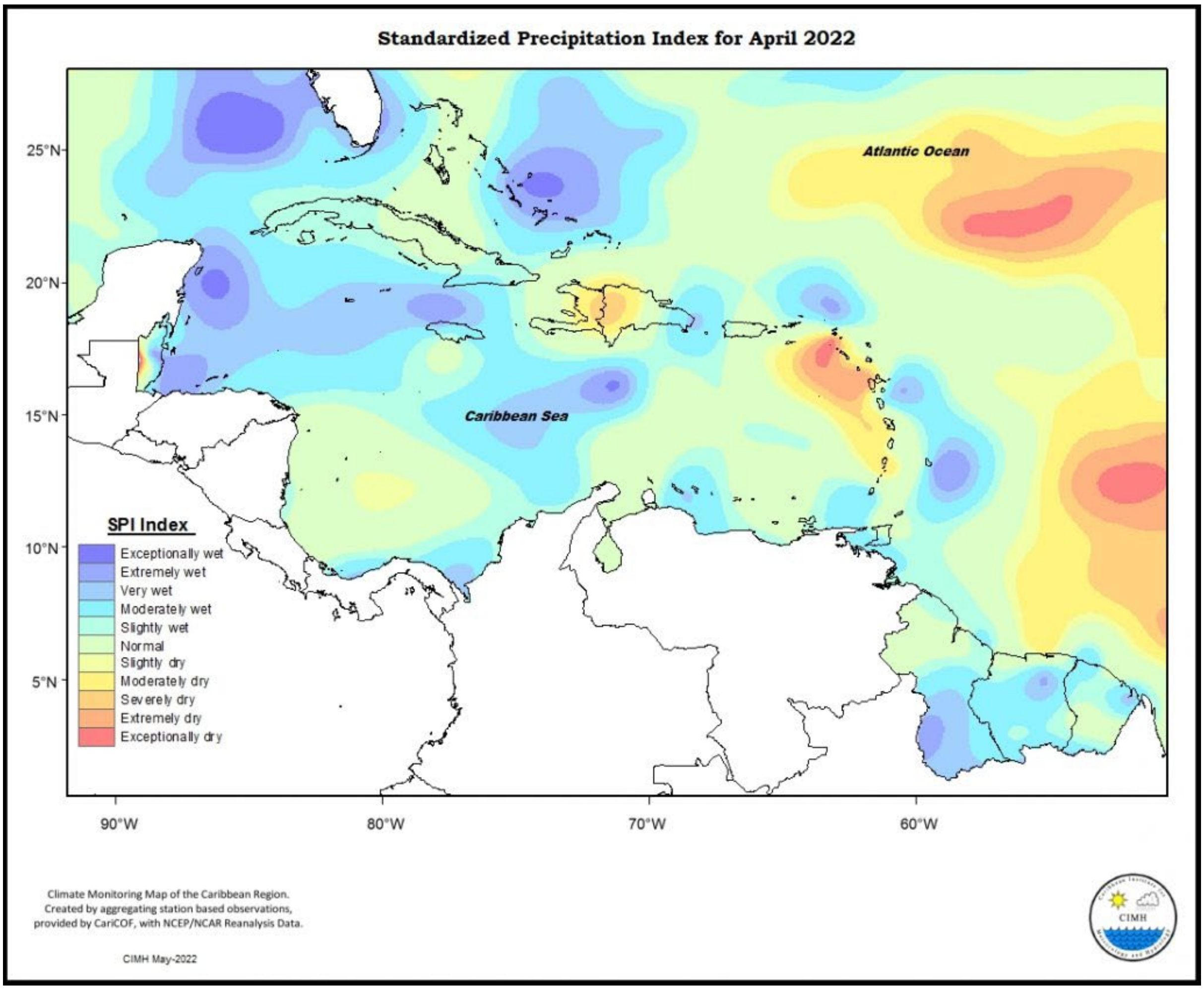


Figure 14 Standardised Precipitation Index monitoring report for April 2022.[39]

Based on an assessment of existing literature, the far north Caribbean islands are characterised by lower meteorological drought hazard, with islands further to the south and east experiencing greater meteorological drought hazard. This pattern reflects in part the fact islands to the south / east currently experience lower rainfall amounts than more northerly islands.

Regarding hydrological drought (which relates to sub-surface and surface water storage), several Caribbean states are already characterised as water scarce,[40] namely Antigua and Barbuda, the Bahamas, Dominica, Grenada, Saint Lucia, Saint Vincent and the Grenadines, Saint Kitts and Nevis, and Cayman Islands. Jamaica, Guyana, Suriname, and Belize have greater access to freshwater sources and so comparatively less drought exposed.

While this qualitative information is valuable, we suggest that additional probabilistic hazard modelling is required before attempting to classify countries into groups based on relative exposure to drought hazard.

[39] https://rcc.cimh.edu.bb/spi-monitor-april-2022/
[40] https://www.preventionweb.net/files/78462_cs5.gar21caribbeandroughtcasestudyf.pdf

Compounding risks: the impact of COVID-19 across the BMCs

The SARS-COV-2 (COVID-19) pandemic has highlighted infectious disease as an emergent driver of risk in many parts of the world. Meteorological and geophysical hazards may interact with infectious disease resulting in a "compounding" of risk. The risk management interventions used to bring epi/pandemic impacts under control, for instance local or national lockdowns and social distancing measures, may inhibit response to and recovery from severe climate events (e.g. a hurricane). Conversely, severe climate events may require the relaxation of pandemic-related restrictions (e.g. to conduct community evacuations) to protect affected individuals in the short-term.

Crucially, the COVID-19 pandemic have not impacted all social groups equally. The Caribbean Policy Research Institute (CAPRI) highlighted that, "*children, youth, women and girls, the poor, informal sector workers and small businesses,* [are] *among the hardest hit*."[41] This being a result of the lockdowns and other restrictions on social activities, which compound existing susceptibilities leading to severe impacts on the most vulnerable members of society.

Considering the impacts of the COVID-19 pandemic by sector, tourism is consistently cited as the worst affected. Prior to the pandemic, the tourism industry was growing strongly across the Caribbean, accounting for 1/3 of the regions GDP, and with growth projected to continue. Despite proving resilient in the face of other catastrophes (e.g., hurricanes), the tourism industry faced losses ten times greater than faced during the 2008-09 financial crisis. A CAPRI report published in August 2021[42] reported that although there was widespread recognition of the need for increased diversification and sustainability of the sector, actions and policy to achieve this was often lacking. Key recommendations include collaboration across the region, to increase competitiveness compared to other key tourism locations, facilitating the development of MSMEs, and standardizing the collection of traveler data.

The United Nations Development Programme, UNICEF, and UN Women have prepared COVID-19 Human and Economic Assessment of Impact (HEAT) Reports for eight countries in the Eastern Caribbean (note that the report for Grenada is not yet available). These reports provide an insight to the compounding impacts that the pandemic has on these countries and the potential implications for disaster risk management more broadly as countries recover. The reports also draw attention to specific impacts on women and vulnerable groups, as well as actions to support these groups.

Country	Description of Impacts	Recommended Actions
Anguilla	Anguilla was still recovering from the impacts of Hurricane Irma (2017) at the onset of the pandemic, which elongated the recovery time. Women are over-represented in the tourism sector, which suffered considerably due to the shutdown of international travel.	Extension of COVID-19 unemployment benefits; establishing a shelter for women victims of gender-based violence, exploring partnerships with the tourism sector.

[41] CAPRI. April 2021. Insult to Injury: The Impact of COVID-19 on Vulnerable Persons and Businesses. Accessible at: https://www.capricaribbean.org/documents/insult-injury-impact-c-19-vulnerable-persons-and-businesses
[42] CAPRI. August 2021. Sun, Sand, and Sustainability: The Way Forward for Caribbean Tourism. Accessible at: https://www.capricaribbean.org/sites/default/files/public/documents/report/sun_sand_and_sustainability_the_way_forward_for_caribbean_tourism_revised_-_august_2021.pdf

Country	Description of Impacts	Recommended Actions
Antigua & Barbuda	Antigua and Barbuda was recovering strongly following the impacts of Hurricane Irma (2017), led in particular by growth in the construction industry. The pandemic reversed much of this growth, notably due to impacts on the tourism industry. Unemployment rose above 30%. COVID-19 spread was contained well, leading to a relatively quicker reopening of national borders after the first wave of the virus.	Key recommendations include the re-introduction of a loan guarantee scheme to support businesses in securing financing for capital investment; engagement with internet service providers and retailers to provide low cost access and technology for remote education; a proactive expansion of the programme to house GBV survivors in hotels.
Barbados	Like many Caribbean states, Barbados is heavily dependent on the tourism industry for foreign exchange. Women constitute around 62% of employment in the accommodation and food services industry. The industry suffered heavily with high unemployment and increased social inequalities.	Enabling the availability of low-cost options for internet access to improve the livelihood potential of the most vulnerable in society and reduce inequalities due to moving to online learning by broadening access to the internet for children in poverty; ensuring social assistance for all who need it, including making unemployment benefits for self-employed individuals permanent to reduce their vulnerability in times of uncertainty.
British Virgin Islands	Impacts to the tourism industry in particular resulted in sever falls in GDP and increases in the rate of unemployment to nearly 20%. Disproportionate impacts on female workers and migrants.	Adapting the framework used to provide financial assistance after Hurricanes Irma and Maria to provide temporary, expanded income support; explore the provision of liquidity for small firms; rigorous assessment of the current level of poverty to inform the design and implementation of an expanded, gender-responsive Public Assistance Programme and the development of a permanent unemployment benefit fund
Dominica	Dominica is less dependent on tourism compared to other states. However, it was still severely impacted by disruption to global supply chains. There was a lack of fiscal space even before the pandemic, limiting the options for both management and recovery.	A grant-funded expansion of the Public Assistance Programme, transitioning of employees of the National Employment Programme to sustainable livelihoods, support for e-learning, increased support for both vertical and horizontal economic diversification and the development of a more resilient social protection system.

Country	Description of Impacts	Recommended Actions
Saint Lucia	Prior to the pandemic, women experienced higher rates of unemployment than men, and were over-represented in lower income parts of the economy (particularly in services). National lockdown resulted in negative GDP trends and increased unemployment.	Encourage economic security through income support and a moratorium on mortgage repayments; also provision of direct support to local indigenous farmers to sustain their livelihoods, among others; the expansion of the Disability Benefit to include adults and victims of sexual abuse and gender-based violence; expansion of home-schooling programmes.
Saint Vincent and the Grenadines	Severe declines in tourism revenue and associated increases in unemployment and social inequality. Increased incidence of gender-based violence.	Focus on supporting MSMEs and general broadening of social safety nets (both horizontal and vertical scaling); training of law enforcement and other front-line personnel to identify and respond to cases of GBV.

Table 11 Summary of COVID-19 impacts and recommended actions across selected BMCs. Information compiled from UNDP, UNICEF, and UN Women COVID-19 HEAT Series.

Key impacts across all the countries listed above include:

- Stalling of recovery from the 2017 hurricane season;
- Disruption to global supply chains resulting in constraints to domestic industries (e.g., construction);
- Widening inequalities, particularly among vulnerable groups (children, youth, women and girls, the poor, informal sector workers, and micro and small businesses), who have inherently higher levels of dependance on others;
- Disruption to the global travel industry resulting in declining tourism revenues, associated increases in unemployment and increased social vulnerabilities.

Common recommended actions include:

- The continuation, and expansion, of income support programmes, some of which were established to support vulnerable groups following the 2017 hurricane season. Specifically aiming to expand the use of existing financial architecture for making payments in an inclusive manner;
- Enabling access to internet and technology to ensure that educational services can continue to operate;
- Measures to support women including dedicated income support, and actions to protect victims of sexual abuse and gender-based violence. Also to provide extended food support to households with women and other vulnerable groups.

2.5 Future climate-related hazards

Many if not all countries across Latin America and the Caribbean are experiencing increasingly marginal environmental conditions as slow onset climate events worsen (sea level rise, temperature rise), whilst also facing increasingly severe extreme events (hurricanes, extreme rainfall, droughts). [43] Slow onset and extreme climate hazards across the region not only constitute a risk to lives, property, and infrastructure, but also to natural assets, and associated ecosystem services, that support the fisheries and agricultural sectors, as well as the communities who rely on them for food security and livelihoods. In the fisheries sector, for example, livelihoods will be affected by projected changes to fish stocks from ocean temperature, and subsequent effects on ocean currents. Moreover, saltwater intrusion caused by sea level rise will affect agricultural land productivity, while crop yields will be negatively affected by more severe droughts, high winds, and extreme rainfall events. Livelihoods across the country will also be impacted indirectly through business interruption and associated lost revenue and income.[44]

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) identifies a significant atmospheric warming trend across the region, averaging 0.20 – 0.30 degrees Celsius per decade since 1990. Alongside this average warming, a decrease in the diurnal temperature range has been observed, with a rising number of very warm days and nights a year. These trends are expected to intensify in the future, reaching a warming of between 2.0 and 4.0 degrees Celsius by the end of the century[45] with up to 95% of all days and nights in a year exceeding the 90th percentile of current temperatures. [46]

Atmospheric warming is accompanied by warming sea surface temperatures (SSTs). Since 1900, SSTs have risen by approximately 1 degree Celsius, with future rise projected to range from 0.39 to 2.15 degrees Celsius per century. This "blanket" increase in temperature across the region could, under the highest emissions scenarios, result in SSTs that exceed 28 degrees Celsius the year-round as early as 2050.[47] Global warming increases the amount of moisture that the atmosphere can hold (increases 7% per 1 degree) and can result in a weakening of atmospheric vertical wind shear, which together produces favorable conditions for convective storms. This said, the determinants of convective rainfall events are complex and linked to regional systems such as ENSO. Due to these seasonally variable impacts, mean precipitation rates are characterised by weak long-term trends. The link between warmer seas and hurricane formation / intensity is similarly complex, though it is possible that hurricanes may become

[43] Intergovernmental Panel on Climate Change. 2021. The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33−144. doi:10.1017/9781009157896.002

[44] Lincoln, S. 2017. Impacts of Climate Change on Society in the Coastal and Marine Environments of Cariibean Small Island Developing States (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017.

[45] Intergovernmental Panel on Climate Change. 2021. The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33−144. doi:10.1017/9781009157896.002

[46] Campbell et al. 2021. Generating Projections for the Caribbean at 1.5, 2.0 and 2.5 ◦C from a High-Resolution Ensemble. Amosphere.

[47] Taylor, M.A., and Stephenson, K.A. 2017. Impacts of Climate Change on Sea Temperature in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017.

more frequent and/or intense. Other significant impacts include increased incidence and severity of coral bleaching, and changes in the distribution and health of mangroves and seagrasses.[48]

Owing in part to the short time period of observation, as well as to the complexity of physical drivers, the impact of atmospheric and ocean warming on tropical cyclone characteristics remains subject to considerable debate. It is generally agreed that under a warmer climate, the region can expect a higher frequency of intense hurricanes (Category 4 and 5), and the IPCC reported with high confidence that the incidence of Category 4 and 5 hurricanes would increase by 80% by the end-of-century under a medium emission scenario. The impacts of this trend may already be materializing. For instance, a study of the 2017 hurricane season showed that the above average number of major hurricanes that year was not primarily caused by La Niña conditions in the Pacific Ocean but rather triggered by pronounced warm sea surface temperatures in the tropical North Atlantic, revealing the pivotal role played by the increase in sea temperature induced by climate change. Regional climate projections suggest increased rainfall rates of 20–30% near the storm eye, 10% for distances over 200km from the center. The same study suggested that the maximum wind speeds associated with the hurricanes are projected to increase by 2–11%.[49] The impact of climate warming on the frequency of hurricanes remains uncertain with no clear trend emerging over the observational record.[50]

Global Climate Models project that the region will likely experience a reduction in annual average precipitation with the strongest drying occurring over the summer in July and August. There remains considerable uncertainty regarding the magnitude of decrease in precipitation, which varies between 5% and 50% depending on the climate model. Each Caribbean sub-region has a slightly different rainfall climatology and timing of rainfall peaks and receives differing rainfall amount. For instance, north and northwest Caribbean (including the Bahamas, Haiti and Jamaica) and those islands of the Lesser Antilles above ~18◦ N latitude show negligible drying (Cayman Islands, Turks and Caicos), while the Caribbean below this latitude shows drying of up to 50% (Antigua and Barbuda, Dominica, Saint Lucia, Saint Kitts and Nevis, Saint Vincent and Grenadines, Monserrat). In Grenada, Trinidad and Tobago and Barbados the drying is expected to exceed 50%. These changes to rainfall patterns, coupled with the significant increase in temperature, poses particular threat to countries at high risk of drought. Global Climate Models suggest that future increases in drought occurrence are likely to be driven by reduced rainfall during the early wet season.[51]

While average precipitation is expected to decrease, the IPCC AR6 states that extreme precipitation across the region will likely increase at global warming levels of 2 degrees and above. The increase in the frequency of heavy precipitation events will be non-linear with more warming and will be higher for rarer events. Increases in the intensity of extreme precipitation events will also depend on changes in atmospheric circulation and storm dynamics.

[48] Taylor, M.A., and Stephenson, K.A. 2017. Impacts of Climate Change on Sea Temperature in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017.
[49] Campbell et al. 2021. Generating Projections for the Caribbean at 1.5, 2.0 and 2.5 ◦C from a High-Resolution Ensemble. Amosphere.
[50] Knutson, T.R., Chung, M.V., Vecchi, G., Sun, J., Hsieh, T-L., and Smith A.J.P. 2021. Climate change is probably increasing the intensity of tropical cyclones. ScienceBrief Review.
[51] Intergovernmental Panel on Climate Change. 2021. The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33−144. doi:10.1017/9781009157896.002

Coastal flood risk is characterised by different dynamics compared to pluvial and fluvial flooding. Coastal inundation across the Caribbean may take various forms ranging from frequent, though relatively less severe, "nuisance flooding", to extreme storm surges associated with hurricane activity. Sea level rise represents a chronic climate pressure which increases the severity and frequency of coastal flooding by increasing the baseline on which extreme water levels are imposed. Relative to the period 1995 – 2014, Global Climate Models project regional sea level rise of 0.1 – 0.2 m by 2040, rising to 0.4 – 1.1 m by 2100, depending on the emissions scenario.[52] It is possible that the magnitude and spatial distribution of storm surge associated extreme water levels could change under future emissions scenarios, through this will depend on changes to hurricane dynamics, nearshore bathymetry, coastal ecosystems, and human interventions. Unpicking these drivers requires local-scale observation and modelling exercises.

2.6 Limitations and data gaps

The hazard analysis presented in this report should be interpreted with due consideration to a number of limitations and data gaps:

- This study necessarily focuses on a limited selection of hazards given the availability of probabilistic hazard modelling datasets from across the BMCs. The focus on tropical cyclone wind and earthquake shaking is well-justified given that these hazards are considerable for the majority of the BMCs. Drought is also tends to impact large spatial extents, though probabilistic risk modelling is not available for the region. Although the impacts of riverine and coastal inundation tend to be more locally concentrated, these hazards can also have severe impacts for exposed locations / populations. Future studies may seek to extend this analysis to consider a wider range of hazards, for example those associated with volcanic activity and mass movements such as landslides.
- This study has focused on acute hazards because these extreme events are typically the target for disaster risk financing. There is also value in considering chronic drivers of disaster risk, for example temperature change and sea level rise, particularly in the context of climate change adaptation investments. This point is covered in Section 4 of the report.
- To determine the hazard faced by specific sub-national regions, natural and public critical infrastructure, and other assets would require access to and use of higher resolution hazard modelling.[53]

Use of sex- and age- disaggregated population data

As part of the hazard analysis, we investigated the potential value in reporting the exposed population disaggregated by sex and age. We undertook the analysis for female, male, population under 15 and population over 65 for all perils. Haiti was chosen as an example country as it has some level of exposure to all four perils of primary interest. Overall, the percentage difference for all disaggregated data for river inundation, coastal inundation, and tropical cyclone was less than 1%. The percentage difference for the earthquake hazard was a slightly higher percentage, although less than 5%. The largest difference between the sex/age disaggregated data and the population as a whole was for people aged over 65

[52] https://interactive-atlas.ipcc.ch/
[53] Rozenberg, Julie; Browne, Nyanya; De Vries Robbé, Sophie; Kappes, Melanie; Lee, Woori; Prasad, Abha. 2021. 360° Resilience : A Guide to Prepare the Caribbean for a New Generation of Shocks. World Bank, Washington, DC. © World Bank.

who were 5% less exposed compared to the population as a whole, and only for certain return periods. This 5% represents 2,500 people, or 0.0002% of Haiti's overall population. Hence performing the sex/age-disaggregated analysis for all BMCs was not justified as there was only marginal difference between categories.

3 Exposure and vulnerability analysis

3.1 Review of approaches to measuring exposure and vulnerability to disaster risk

There is no universal approach to quantifying exposure and vulnerability to disaster risk, although a variety of methods ranging from indicator-based global or national assessments, through site-specific engineering and financial surveys complemented by remotely-sensed data, to qualitative participatory approaches at the local level, have been applied. In this report we adopt an indicator-based approach towards quantifying exposure and vulnerability. This involves three steps: i) identifying and selecting indicators; ii) acquiring or gathering data; and iii) normalizing, weighting and/or aggregating indicators. This sub-section will begin with a high-level review of existing exposure and vulnerability indices, before setting out our approach to assessing vulnerability and exposure.

Among the most widely referenced approaches towards social vulnerability assessment is the Social Vulnerability Index (SoVI) formulated by Cutter et al. (2003).[54] The original SoVI was created by synthesizing 42 socio-economic indicators which were selected following extensive disaster and social science research. These indicators were summarised according to 11 themes through a process called principal components analysis (see Section 6.3). The index has since been updated several times as new data became available, with the most recent comprising 30 indicators. Although the information drivers of social vulnerability provided by the SoVI can be particularly useful, especially when trying to select appropriate indicators, the method used is complex and can be difficult to understand. Moreover, the relative nature of SoVI's values means results can be misinterpreted or misrepresented.[55]

Several efforts have been made to quantify exposure and/or vulnerability to disaster risk in and across the Caribbean. The IDB has estimated the vulnerability of several Caribbean countries using the Prevalent Vulnerability Index (PVI).[56] The PVI is a composite index including 24 indicators that characterise prevalent vulnerability as a function of three factors (or composite indicators): i) exposure in prone areas (PVI_{ES}); ii) socio-economic fragility (PVI_{SF}); and iii) lack of resilience (PVI_{LR}). The PVI provides a measure of both the direct physical impact and the indirect and intangible impacts of hazard events, and is calculated as shown in the formula below (where PVI_{ES}, PVI_{SF}, and PVI_{LR} are the calculated prevalent vulnerability conditions for each composite indicator):

$$PVI = \frac{(PVI_{ES} + PVI_{SF} + PVI_{LR})}{3}$$

The Caribbean Development Bank has developed several vulnerability indices. Early efforts focused on the estimation of the Economic Vulnerability Index (EVI) of small states using a methodology developed by Crowards (2000) and Hartman (2011). The EVI was used to support evidence-based decision making and to guide CDB's development financing architecture and for its concessional resources. In 2019, the Multidimensional Vulnerability Index (MVI) was released. The MVI extended the EVI to include social vulnerability and a climate change component that considers historic natural hazard events and predicts how the environment is likely to cope with future events. It is a function of three dimensions of

[54] Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. Social science quarterly, 84(2), 242-261. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/1540-6237.8402002
[55] Dunning, C.M. and Durden, S.E., 2013. Social vulnerability analysis: A comparison of tools. Institute for Water Resources.
[56] This included three CDB BMCs: Barbados, Jamaica, and Trinidad and Tobago.

vulnerability (economic, social, and environmental) and six sub-indices (export concentration, concentration of export destination, dependence on strategic imports, reliance upon external finance, social vulnerability, and susceptibility to natural hazards and climate change, see Section 6.3) that could be used to support evidence-based policy formulation, planning and decision-making, and guide CDB's development financing architecture.[57]

Most recently, in 2021, the CDB proposed an upgraded measure of vulnerability which better reflects the changing economic, social, and environmental vulnerabilities of small island developing states (SIDS) in the Caribbean region: the Recovery Duration Adjuster (RDA). Building on the MVI, the RDA focuses on measuring the internal resilience capacity of SIDS to better take account of the evolution of vulnerability and resilience in a dynamic and forward-looking manner. At the time of writing, the RDA methodology continues to be refined and the Bank has started conducting various simulations to estimate the internal resilience capacity and duration gap for a representative sample of developed and developing countries.

Building on these previous studies, the approach adopted in this report aims to capture the reality that not all members of society are equally impacted by hazard events. Factors such as age, sex, gender, income, poverty rates, size of household, female-headed versus male-headed households, and educational levels may result in some groups being more vulnerable than others. Gender is an important variable among social factors as it represents a major dimension of social difference. Incorporating gender and cultural norms analyses in vulnerability assessments can help policy makers better understand various degrees of vulnerability.[58] Incorporating gender analyses into vulnerability assessments and understanding gender relations between and among boys, men, girls, and women are essential in determining vulnerability to a range of areas, including to natural hazards, and supports the development and implementation of appropriate policies, programs and solutions all of which are key to closing the gender gap. Thus, understanding vulnerability and developing strategies to overcome it through applying a gender lens (gender analysis) can contribute significantly to addressing the root causes of vulnerability.

Following the first iteration of this report WTW was put in contact with the team responsible for developing the RDA framework. Together, we had fruitful discussion on the background, purpose and methodology of the RDA and on general approaches to quantifying vulnerability and adaptive capacity. There are clear synergies between the analysis presented here and the RDA framework, most notably, the types of vulnerability indicators used – and therefore the data requirements - are very similar. The general approach to quantifying vulnerability is also comparable. However, it is important to emphasize that there are distinct conceptual differences; most fundamentally, this report aims to capture social vulnerability to environmental hazards whereas the RDA focuses on measuring the internal resilience capacity of SIDS. While we would therefore not expect the outputs to line-up directly, we will continue to communicate and collaborate with the RDA team throughout the project to ensure that key learnings are shared.

[57] Ram, J., Cotton, J., Frederick, R., & Elliott, W. (2019). Measuring vulnerability: A multidimensional vulnerability index for the Caribbean. *CDB Working Paper No. 2019/01, Caribbean Development Bank*.
[58] In this context, the norms referred to pertain to norms defining gender relations amongst boys, men, girls and women.

3.2 Quantifying exposure and vulnerability to disaster risk across the BMCs

3.2.1 Methodology

Expert judgement was combined with a review of existing exposure and vulnerability indices to identify a preliminary list of appropriate indicators across the BMCs. The literature review assessed 18 conceptual frameworks, guidance documents, and indices relating to the conduct of vulnerability assessments; this included literature published by a variety of international development agencies and development financing organizations such as the United Nations Office for Disaster Risk Reduction (UNDRR), the United Nations Development Programme (UNDP), and the IDB, as well as non-governmental organizations (NGOs) and academic literature. Some of the vulnerability indicators reviewed at this stage are presented in Section 6.3.

Next, the most appropriate indicators from this preliminary list were selected and data gathered. The selection process was guided by several criteria:

- This assessment will focus primarily on the national scale and so indicators must be available for this level;
- The indicators should be relatively simple and transparent, so they can be easily understood;
- Data for an indicator should be available for at least 70% of BMCs and be less than 10 years old, to ensure completeness and relevance of data (see section 3.4 for a list of notable gaps in data availability);
- Wherever possible, data for an indicator should be sex- and age disaggregated;
- Indicators can be expected to be available in the future should the research be repeated; and
- Overseas Territories (OST: Anguilla; the British Virgin Islands; the Cayman Islands; Montserrat; and the Turks and Caicos Islands) were not included in this analysis because data and other policy-related information related to OSTs are often bundled with data from the UK.

Each indicator was then defined as an indicator of either exposure, sensitivity, or adaptive capacity, in line with the IPCC definitions.

Exposure indicators capture value at risk from hazard events. The literature review revealed that indicators of exposure generally include population density and urban population rates, livelihoods, building type and density, natural assets and environmental functions, services, and resources which reflect the people, places, and settings that could be adversely affected by a hazardous event. Given the focus of this project on vulnerable populations, several of exposure indicators that we have selected relate to people, for instance, population density and percentage of the population living in urban areas. The percentage of the overall population that is female is also included. Alongside the population indicators, we also include more conventional proxies for exposure; for example, a regionally consistent indicator of critical infrastructure. Given the high dependence of many Caribbean states on natural capital to support key industries (e.g., tourism, fisheries), the final exposure indicator aims to capture the value of natural capital and associated ecosystem services.

Vulnerability is captured using two indicator classes, sensitivity and adaptive capacity, whereby:

Vulnerability = Sensitivity / Adaptive Capacity

High sensitivity values contribute to higher vulnerability, while high adaptive capacity values can contribute to lower vulnerability.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by variability or change. The sensitivity indicators selected for this analysis aim to capture the proportion of the population that are vulnerable to disaster risk; for example, the young and the elderly (represented by percentage of the population <15 and >65 respectively). A number of gender-related indicators are also included, namely female life expectancy at birth and ratio of female-to-male labor force participation. The sensitivity of the environment is also captured using the Environmental Performance Index, which captures environmental health and ecosystem vitality. Finally, the Building Quality Control Index is included as a vulnerability indicator that is more akin to traditional risk assessment (i.e., that requires an understanding of how built structures will respond when exposed to hazardous events). This index represents the quality of the built environment, and is predicated on information about building codes across the region and the extent to which they are implemented.[59]

Adaptive capacity captures the ability of populations to adjust to potential damage, take advantage of potential opportunities, and respond to consequences. In this analysis, adaptive capacity is represented by several macroeconomic and socioeconomic indicators including the Human Development Index, GDP per capita, and total public debt as a percentage of GDP. Governance structures are also important to disaster response, and are represented here through the Government Effectiveness Index, Voice and Accountability Index, and Control of Corruption Index. Vulnerable populations and gender-related indicators of adaptive capacity include educational expenditure as a percentage of GDP, female secondary school enrolment, and the proportion of seats held by women in national parliaments.

An exception to the selection process described above was made for poverty rate data, which was included as an indicator at the request of CDB. Poverty is widely recognized as an important driver and consequence of disasters, however, systematic and consistent collection of poverty data across the BMCs is lacking (see section 3.5 for an overview of the data limitations associated with this analysis). The poverty data presented below has been provided by the CDB's RDA team and is derived from World Bank sources and BMCs' National Statistical offices. The data has been collected for the most recent year in the period 2006-2017 (no poverty data for the BMCs considered here are available after 2017) and in general each country has only one or two years of reported data available.

3.2.2 Results

Table 12 sets out the selected exposure, sensitivity, and adaptive capacity indicators and the respective data sources.

[59] The BQCI represents the most recent quantification of the state of built environment quality across the region and, as such, is well-suited to the needs of this project. We recognise, however, that there has been, and continues to be, substantial efforts to expand the use – and enforcement – of building codes in individual countries and sub-regions – including those involving CDEMA, CDB, CROSQ, and PAHO (amongst others) – and that such efforts may not be fully represented in the BQCI.

Indicator	Justification	Source
Exposure		
Population density (people per km^2)	Population density may affect the level of exposure to disasters as population-dense areas tend to be more infrastructurally crowded, meaning that there is a danger of injury and loss of property in the event of a disaster. Furthermore, densely populated regions will experience a greater overall demand for first aid or medical response, meaning a higher risk of individuals deteriorating or dying before they can receive appropriate medical aid.	World Bank[60]
Population living in urban areas (% of total population)	Similar to population density, the higher the proportion of the population living in urban areas the great the assumed exposure of people and property in the event of a disaster.	World Bank
Coral reef area exposed to high or very high threat (% of land area)	Natural capital and associated ecosystem services underpin livelihoods and economic activity across many Caribbean states. Coral reefs are particularly important to support tourism and fisheries. This indicator captures the proportion of total reef area under threat, scaled based on the total land area of the country, on the assumption that in countries where reef area is greater relative to land area, the importance of reefs in supporting people and economies will also be higher.	World Resources Institute Reefs at Risk Revisited[61] and Reefs at Risk: Caribbean[62]
Critical Infrastructure Spatial Index (CISI)	The CISI is a spatial index that aggregates high-resolution geospatial OpenStreetMap (OSM) data of 39 CI types that are categorised under seven overarching CI systems. The dataset is available at 0.25 degree resolution across the Caribbean and can be used to identify hotspots of critical infrastructure exposure. It is expected that countries	Nirandjan et al. 2022[63]

[60] Available at: https://databank.worldbank.org/home.aspx
[61] Available at: https://www.wri.org/research/reefs-risk-revisited
[62] Available at: https://files.wri.org/d8/s3fs-public/pdf/reefs_caribbean_full.pdf
[63] Nirandjan, S., Koks, E.E., Ward, P.J. *et al.* A spatially-explicit harmonized global dataset of critical infrastructure. *Sci Data* **9,** 150 (2022). https://doi.org/10.1038/s41597-022-01218-4

Indicator	Justification	Source
	with a higher CISI score may expect their critical infrastructure to be more exposed to natural hazards.	
Multi-hazard average annual loss as a percentage of GDP	The multi-hazard average annual loss (AAL) is the expected average losses (over a long period of time) from earthquake, flood and hurricane hazards. It is calculated as the sum of losses from each year in a catalogue divided by the number of years in the catalogue, where the catalogue takes into account all the disasters that could occur in the future. Here, we consider AAL as a percentage of a country's GDP, as set out in the GAR15. This indicator illustrates how the exposure of assets to disaster risk is distributed across countries.	UNISDR, 2015[64]
Sensitivity		
Life expectancy at birth, sex-disaggregated	Life expectancy is a basic statistic that indicates public health achievements and social development, including the health system, infrastructure, and accurate vital statistics. Countries with lower life expectancies may therefore expect the population to be more adversely affected by hazardous events.	World Bank
Infant mortality rate	Infant mortality measures child survival and reflects the social, economic and environmental conditions in which children (and others in society) live, including their health care. Mortality rates are often used to identify vulnerable populations and countries with higher infant mortality rates may therefore expect the population, and particularly children, to be more adversely affected by hazardous events.	World Bank
Child dependency ratio Old age dependency ratio	The young and very old are two social groups which may be more adversely affected during and after natural hazard events due to reduced physical mobility, diminished sensory awareness, chronic health conditions, and social and economic limitations that prevent adequate preparation and hinder adaptability. We capture these groups using two indicators: the child and old-age dependency ratios, defined as the ratio of the	UNICEF[65] UNICEF

[64] UNISDR. "The human cost of natural disasters: A global perspective." (2015).
[65] Available at: https://data.unicef.org/resources/data_explorer/

Indicator	Justification	Source
	population aged under 15 and 65+, respectively, to the number of persons of working age (15-64 years old).	
Unemployment (% of total labor force)	Unemployed people may be more adversely affected by natural hazards because of inadequate income and resources to support themselves and recover. See also "ratio of female-to-male labor force participation rate".	Ministry of Finance and Corporate Governance, Antigua and Barbuda[66], Central Statistics Office of Dominica[67], World Bank
Poverty rate	The proportion of the population living below the national poverty line. Poverty is widely recognized in the literature as a driver of vulnerability, with poorer people more likely to live in (cheaper) disaster-prone areas and unable to afford to undertake disaster risk reduction activities. People living in poverty also have limited assets to buffer disaster loss, potentially driving them further into poverty. Countries with a higher poverty rate may expect to be more adversely affected by natural hazards.	World Bank Recovery Duration Adjuster Team at the Caribbean Development Bank
Ratio of female-to-male labor force participation rate	The ratio of female-to-male labor force participation rate is calculated by dividing female labor force participation rate by male labor force participation rate and multiplying by 100. The labor force participation rate is the proportion of the population age 15 and older that is economically active. Countries with lower ratio of female-to-male labor force participation rate may therefore expect women to be more adversely affected by hazardous events.	World Bank (ILO estimates)
Environmental Performance Index	The 2020 Environmental Performance Index (EPI) provides a data-driven summary of the state of sustainability around the world. Using 32 performance indicators across 11 issue categories, the EPI ranks 180 countries on environmental health and ecosystem	Environmental Performance Index 2020[68]

[66] Available at: https://statistics.gov.ag/subjects/labour/unemployment-and-unemployment-rate-by-sex-and-age-group-2015/
[67] Available at: https://stats.gov.dm/subjects/labour-force/labour-force-characteristics-by-sex-age-2011/
[68] Wendling, Z. A., Emerson, J. W., de Sherbinin, A., Esty, D. C., et al. (2020). 2020 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. epi.yale.edu

Indicator	Justification	Source
	vitality. These indicators provide a gauge at a national scale of how close countries are to established environmental policy targets, and therefore countries with a lower EPI score may expect to be more adversely affected by disasters.	
Building Quality Control Index	The Building Quality Control Index is based on six indices: the quality of building regulations, quality control before, during, and after construction, liability and insurance regimes, and professional certifications indices. It is expected that in countries with lower Building Quality Control Index scores, the impact of disaster events will be more severe.	World Bank and Global Facility for Disaster Reduction and Recovery[69]
Adaptive Capacity		
Human Development Index	The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living. Higher human development means potentially greater capacity to prepare for and adapt to hazardous situations.	United Nations Development Programme
GDP per capita	GDP per capita is used here as a measure of economic security, with the assumption that the higher the GDP per capita the greater the ability to cope in the event of a disaster.	World Bank
Total public debt as a % GDP	Even where political will is present, access to finance is more difficult when there are limited resources to dedicate towards pursuing opportunities / offering co-financing incentives, and further inhibited by increasingly unsustainable public debt, specifically in the case of SIDS.	Economic Commission for Latin America and the Caribbean, Statistical Database and Publications[70]

[69] World Bank and GFDRR. 2020. The Building Regulation for Resilience Programme. Resilient Building Regulation in the Caribbean. Accessible at: https://openknowledge.worldbank.org/bitstream/handle/10986/36414/360-Resilience-A-Guide-to-Prepare-the-Caribbean-for-a-New-Generation-of-Shocks-The-Building-Regulation-for-Resilience-Program-Resilient-Building-Regulation-in-the-Caribbean.pdf?sequence=5
[70] Available at: https://statistics.cepal.org/portal/cepalstat/index.html?lang=en

Adaptive Capacity		
Educational expenditure as a % of GDP	Educational expenditure as a % of GDP is a measure of the importance the government places on education. Education is an important vulnerability indicator that can imply a residents' income, quality of life, job opportunities. It can also affect residents' survival and longer-term wellbeing following disaster events because education shapes the population's capacity to respond to, cope with, and recover from natural disasters.	United Nations Sustainable Development Goals Indicators Database[71]
School enrollment, secondary, sex-disaggregated (% gross)	A gender-related indicator that captures the proportion of females enrolled in secondary school education. Like educational expenditure, school enrollment is a measure of the importance the government places on education - specifically the education of girls – with the assumption that more education means greater capacity to respond to and cope with disasters. This may also be a proxy for wider societal opportunities that are open to women.	World Bank
Proportion of population using basic drinking water services	Access to basic water services may act as a proxy for housing conditions and the quality of residential environments, which may exacerbate susceptibility to disasters. Furthermore, there is an implied gendered element to this indicator.[72]	United Nations Sustainable Development Goals Indicators Database[73]
Government Effectiveness Index	Strong overall governance systems may reduce the potential for severe disaster impacts across the hazard cycle. Here, the strength of governance systems in each BMC is captured using three indices elaborated by the World Bank Group: (1) The government effectiveness index, a measure of the quality of public services, civil service, policy formulation, policy implementation and credibility of a government's commitment to raise these qualities or keep them high;	World Bank Worldwide Governance Indicators[74]
Control of Corruption Index	(2) The control of corruption index, which captures the perceived extent to which public power is exercised for private gain, and;	World Bank Worldwide Governance Indicators
Voice and Accountability Index	(3) The voice and accountability index, which captures whether the population feels that their voice is heard and that they can hold the government accountable.	World Bank Worldwide Governance Indicators

[71] Available at: https://unstats.un.org/sdgs/dataportal
[72] According to the WHO "Women and children spend millions of hours each year fetching water. The chore diverts their time from other important activities (for example attending school, caring for children, participating in the economy). When water is not available on premises and has to be collected, women and girls are much more likely than men and boys to be the main water carriers for their families." https://www.who.int/data/gho/indicator-metadata-registry/imr-details/4818
[73] Available at: https://unstats.un.org/sdgs/unsdg
[74] Available at: http://info.worldbank.org/governance/wgi/

Adaptive Capacity		
Proportion of seats held by women in national parliaments (%)	This is a gender-related indicator which captures the proportion of women in prominent governance positions. When more women occupy these positions, it is more likely that gender-sensitive approaches towards disaster response will be incorporated into policy and implemented.	World Bank

Table 12 Selected exposure, sensitivity and adaptive capacity indicators and the respective data sources. See section 3.4 for a list of notable indicator gaps.

To allow for comparison between the indicators, the raw data was normalised using a scale of 0.00 to 1.00, where a value of 1.00 (0.00) could be defined as the most (least) exposed or sensitive or with the most (least) capacity to adapt.

$$N = \frac{I^x - I^{min}}{I^{max} - I^{min}}$$

Where:

N = Normalised indicator value

I^x = Indicator value of an individual country

I^{min} = Minimum indicator value across all countries in the analysis

I^{max} = Maximum indicator value across all countries in the analysis

This method provides a static view of the vulnerability of a country at a point in time, relative to other BMCs.

Exposure

There is no clear pattern of exposure across the five indicators considered. Barbados has the highest normalised score for population density, but relative few people living in urban areas, while in The Bahamas the opposite is true. In this case, a normalised value of 1.00 suggests that a country is the most exposed of the BMCs considered, while a normalised value of 0.00 suggests it is the least exposed. The countries in red are in the upper quartile of normalised scores for that exposure indicator; those in pale yellow are in the lower quartile; and those in orange and golden yellow are between the median-upper quartile and the median-lower quartile, respectively. The gray cells show that there are no data available. Guyana and Belize have consistently lower normalised exposure scores across all indicators.

In the context of gender, it is important to point out that the percentage of the overall population that is female varies only slightly between BMCs, with the maximum value (51.73%, Antigua and Barbuda) only around 5% higher than the minimum (49.33%, Saint Vincent and the Grenadines). To emphasize this point, the average female population across all BMCs is 50.49 (as % of the total population) and the standard deviation is 0.80. In contrast, the average population density is 224 people per km^2 and the standard deviation is 186.

Sensitivity

A more consistent pattern begins to emerge across the seven sensitivity indicators, with Guyana and Haiti scoring relatively high across all normalised values. Like exposure, a normalised value of 1.00 suggests the highest sensitivity relative to all BMCs considered, while a normalised value of 0.00 suggests the lowest sensitivity. Once again, The Bahamas has a relatively low normalised score across most indicators, as does Jamaica, suggesting relatively low sensitivity.

Gender-related indicators, including female life expectancy at birth and the ratio of female-to-male labor force participation, reveal considerable variation in sensitivity between BMCs. For example, female life expectancy at birth ranges from 65.5 years in Haiti to 78.7 years in Antigua and Barbuda, a difference of over 13 years. Similarly, the ratio of female-to-male labor force participation rate ranges considerably from a high of around 90% in Haiti and The Bahamas and to a low of around 60% in Guyana and Belize.

Adaptive Capacity

Haiti consistently scores the lowest across all normalised indicator values for adaptive capacity, including the Human Development Index, government effectiveness, and the proportion of seats held by women in national parliaments. A normalised value of 1.00 suggests the highest adaptive capacity relative to all BMCs considered, while a normalised value of 0.00 suggests the lowest capacity. The countries in red are in the lower quartile of normalised scores for that adaptive capacity indicator; those in pale yellow are in the upper quartile; and those in orange and golden yellow are between the median-lower quartile and the median-upper quartile, respectively. The gray cells show that there are no data available. Suriname and Belize also scored relatively low across all normalised values, although Belize does have the highest educational expenditure (as a % of GDP) of all countries. On the other hand, Barbados, The Bahamas, and Trinidad and Tobago have relatively high normalised values. Interestingly, half of the BMCs considered have a negative Government Effectiveness Index score, suggesting weaker than average government performance as it relates to the efficiency and effectiveness of their public sector to deliver goods and services as compared to the 180 countries in the index.

In the context of gender, the average proportion of females enrolled in secondary school (% gross) across all BMCs is relatively high at 98.8%, ranging from 78.9% in the Bahamas to 122.1% in Grenada. Conversely, the average proportion of seats held by women in national parliaments is 22.6% and ranges from a minimum of 2.5% in Haiti to 46.7% in Grenada.

	Exposure									
Indicator	**Population density**		**Population living in urban areas**		**CISI Maximum Infrastructure Intensity**		**Coral Reef Area at High or V. High Threat**		**Multi-hazard average annual losses (AAL)**	
Unit	People per square km of land		% of total population		Index ranging from 0 (no intensity) to 1 (highest intensity)		% of land area		% of GDP	
	Data	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**
Antigua & Barbuda	223	0.33	24.4	0.09	0.14	0.20	0.25	0.42	4.30	0.89
Barbados	668	1.00	31.2	0.19	0.09	0.13	0.21	0.34	0.74	0.07
Belize	17	0.02	46.0	0.42	0.00	0.00	0.02	0.02	1.39	0.22
Dominica	96	0.14	71.1	0.81	0.04	0.06	0.09	0.15	3.38	0.68
Grenada	331	0.49	36.5	0.27	0.03	0.04	0.37	0.62	0.65	0.05
Guyana	4	0.00	26.8	0.12	0.06	0.09	NULL		0.42	0.00
Haiti	414	0.62	57.1	0.59	0.55	0.80	0.05	0.06	0.70	0.06
Jamaica	273	0.41	56.3	0.58	0.44	0.63	0.06	0.09	0.65	0.05
Saint Kitts & Nevis	205	0.30	30.8	0.19	0.08	0.11	0.59	1.00	2.00	0.36
Saint Lucia	301	0.45	18.8	0.00	0.13	0.19	0.15	0.23	1.39	0.22
Saint Vincent & the Grenadines	284	0.42	53.0	0.53	0.22	0.32	0.22	0.37	0.93	0.12
Suriname	4	0.00	66.1	0.73	0.26	0.38	NULL		0.55	0.03
The Bahamas	39	0.05	83.2	1.00	0.69	1.00	0.07	0.11	4.79	1.00
Trinidad & Tobago	273	0.40	53.2	0.53	0.41	0.60	0.01	0.00	0.90	0.11

Table 13 Raw and normalised ("norm.") data for selected exposure indicators across selected BMCs. A normalised value of 1.00 suggests that a country is the most exposed of the BMCs considered, while a normalised value of 0.00 suggests it is the least. The countries in red are in the upper quartile of normalised scores for that exposure indicator; those in pale yellow are in the lower quartile; and those in orange and golden yellow are between the median-upper quartile and the median-lower quartile, respectively. The gray cells show that there are no data available.

Sensitivity												
Indicator	**Child dependency ratio**		**Old-age dependency ratio**		**Life expectancy at birth (female)**		**Life expectancy at birth (male)**		**Infant mortality rate**		**Unemployment**	
Unit	Ratio of the population age under 15 to the number of persons of working age (15-64 years old)		Ratio of the population age 65+ to the number of persons of working age (15-64 years old)		years		years		Number of infants dying before reaching one year of age per 1,000 live births		% of total labor force	
	Data	**Norm.**	**Data**	**Data**	**Norm.**	**Data**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**
Antigua & Barbuda	31.7	0.26	14.1	0.35	78.7	0.00	73.8	0.00	5.4	0.00	NULL	
Barbados	25.0	0.01	25.9	1.00	78.3	0.04	73.4	0.03	11.4	0.15	10.1	0.44
Belize	43.5	0.71	7.8	0.00	73.4	0.40	67.7	0.48	10.0	0.11	6.5	0.20
Dominica	26.5	0.07	14.9	0.39	NULL		NULL		31.7	0.64	NULL	
Grenada	35.9	0.42	15.1	0.40	76.1	0.20	71.2	0.21	14.5	0.22	NULL	
Guyana	42.1	0.66	11.2	0.19	69.0	0.73	64.4	0.75	23.8	0.45	13.9	0.69
Haiti	51.3	1.00	8.4	0.03	65.5	1.00	61.2	1.00	46.7	1.00	13.5	0.66
Jamaica	34.3	0.36	13.8	0.33	78.4	0.03	73.6	0.02	11.4	0.15	7.7	0.28
Saint Kitts & Nevis	27.2	0.09	12.5	0.26	NULL		NULL		12.6	0.17	NULL	
Saint Lucia	24.7	0.00	14.8	0.38	78.2	0.04	72.8	0.08	22.0	0.40	15.6	0.80
Saint Vincent & the Grenadines	31.6	0.26	14.9	0.39	75.4	0.25	71.1	0.22	12.9	0.18	18.6	1.00
Suriname	39.8	0.57	11.0	0.18	74.7	0.30	68.3	0.44	15.7	0.25	6.9	0.23
The Bahamas	30.1	0.20	11.4	0.20	78.6	0.01	72.6	0.10	10.5	0.12	10.1	0.44
Trinidad & Tobago	29.0	0.16	17.5	0.53	74.3	0.33	67.3	0.52	14.8	0.23	3.5	0.00

Table 14 Raw and normalised ("norm.") data for selected sensitivity indicators across selected BMCs. A normalised value of 1.00 suggests that the country is the most sensitive of the BMCs considered, whilst a normalised value of 0.00 suggests it is the least. The countries in red are in the upper quartile of normalised scores for that sensitivity indicator; those in pale yellow are in the lower quartile; and those in orange and golden yellow are between the median-upper quartile and the median-lower quartile, respectively. The gray cells show that there are no data available.

Sensitivity (cont.)								
Indicator	**Poverty rate**		**Ratio of female-to-male labor force participation rate**		**Building Quality Control Index**		**Environmental Performance Index**	
Unit	% of population living below national poverty lines		% of total labor force					
	Data	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**
Antigua & Barbuda	18.30	0.12	NULL		9.00	0.38	48.5	0.00
Barbados	17.18	0.09	87.6	0.10	6.50	0.69	45.6	0.13
Belize	40.99	0.62	60.4	1.00	7.00	0.63	41.9	0.31
Dominica	30.30	0.38	NULL		8.00	0.50	44.6	0.18
Grenada	37.70	0.54	NULL		5.00	0.88	43.1	0.25
Guyana	36.10	0.51	62.3	0.94	4.00	1.00	35.9	0.59
Haiti	58.50	1.00	87.5	0.10	5.00	0.88	27	1.00
Jamaica	19.30	0.14	80.4	0.34	12.00	0.00	48.2	0.01
Saint Kitts & Nevis	23.34	0.23	NULL		7.00	0.63	NULL	
Saint Lucia	25.12	0.27	85.8	0.16	10.50	0.19	43.1	0.25
Saint Vincent & the Grenadines	30.20	0.38	71.1	0.64	8.00	0.50	48.4	0.00
Suriname	47.21	0.75	66.2	0.81	6.50	0.69	45.2	0.15
The Bahamas	12.90	0.00	90.5	0.00	12.00	0.00	43.5	0.23
Trinidad & Tobago	NULL		68.5	0.73	10.00	0.25	47.5	0.05

Table 14 (cont.) Raw and normalised ("norm.") data for selected sensitivity indicators across selected BMCs. A normalised value of 1.00 (red) suggests that the country is the most sensitive of the BMCs considered, whilst a normalised value of 0.00 (green) suggests it is the least. The countries in red are in the upper quartile of normalised scores for that sensitivity indicator; those in pale yellow are in the lower quartile; and those in orange and golden yellow are between the median-upper quartile and the median-lower quartile, respectively. The gray cells show that there are no data available.

Adaptive Capacity												
Indicator	**Human Development Index**		**GDP per capita**		**Total public debt [Inv]**		**Educational expenditure as a % of GDP**		**School enrolment, secondary, female (gross)**		**School enrolment, secondary, male (gross)**	
Unit			(current US$)		% of GDP		%		% gross		% gross	
	Data	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**
Antigua & Barbuda	0.78	0.88	13,993	0.53	84.1	0.57	NULL		109.1	0.70	113.3	0.90
Barbados	0.81	1.00	15,374	0.59	142.2	0.00	4.4	0.35	105.7	0.62	102.4	0.69
Belize	0.72	0.68	4,115	0.12	118.2	0.23	7.6	1.00	86.9	0.18	83.7	0.32
Dominica	0.74	0.76	7,004	0.24	97.1	0.44	5.6	0.60	102.9	0.56	100.3	0.65
Grenada	0.78	0.88	9,262	0.33	70.6	0.70	3.2	0.11	122.1	1.00	118.2	1.00
Guyana	0.68	0.57	6,956	0.24	NULL		5.5	0.58	99.2	0.47	96.3	0.57
Haiti	0.51	0.00	1,272	0.00	39.9	1.00	2.8	0.03	NULL		NULL	
Jamaica	0.73	0.74	4,665	0.14	103.3	0.38	5.2	0.51	83.4	0.11	82.7	0.31
Saint Kitts & Nevis	0.78	0.88	18,438	0.72	46.4	0.94	2.6	0.00	108.7	0.69	105.1	0.74
Saint Lucia	0.76	0.82	8,805	0.31	85.0	0.56	3.3	0.14	91.0	0.28	92.8	0.50
Saint Vincent & the Grenadines	0.74	0.75	7,278	0.25	82.8	0.58	5.7	0.62	108.7	0.69	105.9	0.76
Suriname	0.74	0.75	4,917	0.15	111.4	0.30	NULL		88.6	0.23	67.1	0.00
The Bahamas	0.81	1.00	25,194	1.00	99.5	0.42	NULL		78.9	0.00	74.9	0.15
Trinidad & Tobago	0.80	0.94	15,426	0.59	68.4	0.72	NULL		NULL		NULL	

Table 15 Raw and normalised (“norm.”) data for selected adaptive capacity indicators across selected BMCs. A normalised value of 1.00 suggests that the country has the most capacity of the BMCs considered, whilst a normalised value of 0.00 suggests it has the least. The countries in red are in the lower quartile of normalised scores for that adaptive capacity indicator; those in pale yellow are in the upper quartile; and those in orange and golden yellow are between the median-lower quartile and the median-upper quartile, respectively. The gray cells show that there are no data available.

Adaptive Capacity (cont.)										
Indicator	**Proportion of population using basic drinking water services**		**Voice and accountability index**		**Government effectiveness index**		**Control of Corruption index**		**Proportion of seats held by women in national parliaments**	
Unit	%		Estimate of governance (ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)						%	
	Data	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**	**Data**	**Norm.**
Antigua & Barbuda	96.7	0.93	0.74	0.80	-0.15	0.69	0.28	0.63	11.1	0.19
Barbados	98.5	0.99	1.13	1.00	0.49	0.92	1.23	1.00	20.0	0.40
Belize	98.4	0.98	0.53	0.69	-0.65	0.51	-0.19	0.44	9.7	0.16
Dominica	95.4	0.89	0.88	0.87	-0.18	0.68	0.56	0.74	34.4	0.72
Grenada	95.6	0.90	0.69	0.78	-0.07	0.72	0.36	0.66	46.7	1.00
Guyana	95.6	0.90	0.21	0.54	-0.44	0.58	-0.15	0.46	35.7	0.75
Haiti	66.7	0.00	-0.84	0.00	-2.03	0.00	-1.32	0.00	2.5	0.00
Jamaica	91.0	0.76	0.63	0.74	0.41	0.90	-0.01	0.52	28.6	0.59
Saint Kitts & Nevis	98.6	0.99	0.82	0.84	0.70	1.00	0.38	0.67	25.0	0.51
Saint Lucia	96.9	0.94	0.88	0.87	0.15	0.80	0.51	0.72	18.2	0.35
Saint Vincent & the Grenadines	95.1	0.88	0.91	0.89	0.15	0.80	0.81	0.84	16.7	0.32
Suriname	98.0	0.97	0.42	0.64	-0.54	0.55	-0.43	0.35	29.4	0.61
The Bahamas	98.9	1.00	0.92	0.89	0.45	0.91	1.14	0.97	12.8	0.23
Trinidad & Tobago	98.9	1.00	0.64	0.75	0.18	0.81	-0.11	0.47	26.2	0.54

Table 15 (cont.) Raw and normalised ("norm.") data for selected adaptive capacity indicators across selected BMCs. A normalised value of 1.00 suggests that the country has the most capacity of the BMCs considered, whilst a normalised value of 0.00 suggests it has the least. The countries in red are in the lower quartile of normalised scores for that adaptive capacity indicator; those in pale yellow are in the upper quartile; and those in orange and golden yellow are between the median-lower quartile and the median-upper quartile, respectively. The gray cells show that there are no data available.

3.3 Aggregated exposure and vulnerability scores

The normalised indicator scores calculated in section 3.2.2 can be aggregated and combined to give a regional view of exposure and vulnerability. As with indicator selection, there is no standard approach for indicator aggregation and combination, and the literature covers several aggregation methods, each with their own strengths and weaknesses.

We adopt the following method to aggregate and combine indicator values:

- First, any missing (or "NULL") data is replaced by the average indicator value across all BMCs for calculation purposes;
- Then, exposure, sensitivity and adaptive capacity indicator values are aggregated using the arithmetic mean to give a single score for each risk component; and
- Vulnerability is calculated as sensitivity divided by adaptive capacity, as set out in the IPCC's Fifth Assessment Report.

Results are presented in Table 16. Data completeness, defined as the proportion of indicators for which data is available, is also presented.

	Exposure	Sensitivity	Adaptive Capacity	Vulnerability (S/AC)	Complete-ness
Antigua & Barbuda	0.38	0.21	0.66	0.31	88%
Barbados	0.35	0.27	0.69	0.39	100%
Belize	0.14	0.45	0.48	0.92	100%
Dominica	0.37	0.37	0.65	0.57	85%
Grenada	0.30	0.41	0.73	0.55	92%
Guyana	0.10	0.65	0.56	1.16	92%
Haiti	0.43	0.77	0.19	4.14	92%
Jamaica	0.35	0.16	0.52	0.32	100%
Saint Kitts & Nevis	0.39	0.32	0.73	0.44	81%
Saint Lucia	0.22	0.26	0.57	0.45	100%
Saint Vincent & the Grenadines	0.35	0.38	0.67	0.57	100%
Suriname	0.29	0.44	0.45	0.97	92%
The Bahamas	0.63	0.13	0.63	0.21	96%
Trinidad & Tobago	0.33	0.32	0.66	0.49	85%

Table 16 Aggregated exposure and vulnerability scores for each BMC.

3.4 Future socioeconomic trends

Alongside future climate scenarios, as were addressed in section 2.4, it is also important to consider future socioeconomic scenarios in the context of climate change. Vulnerability is not evenly distributed among the Caribbean countries, and varies considerably due to myriad factors, including though not limited to, demographics, poverty, gender equality, and participation into local decision-making. Recognising the need to consider coupled climate and socioeconomic scenarios, the IPCC have sought to assess how socioeconomic vulnerability will change based on climate science and policy. The result is the development of Shared Socioeconomic Pathways (SSPs), five pathways describing alternative socio-economic developments (such as population, urbanisation, economic growth, and education), intended to complement climate models. They aim to paint a picture of how the world will evolve without climate policy and how challenging it will be to address mitigation and adaptation. The vulnerability section of this Risk Audit report incorporates various indicators relating to population, the built environment and natural capital as three key factors to explore and illustrate a realistic view of the Caribbean region's socioeconomic vulnerability to natural hazards.

Population across the Caribbean is characterised through a host of elements, such as density in urban and rural centers, propensity of poverty, access to family planning, rates of urbanisation and eco-migration (communities that have relocated from lands impacted by climate change, typically to urban centers). The higher the population density, particularly dependents or aging persons, the greater vulnerability the population faces to climate shocks and stresses.[75] While population has been steadily rising across all BMCs over the last 50 years, population growth across the Caribbean is projected to slow down, primarily due to decreased fertility rates and negative migration balances.[76,77] This could mean reduced socioeconomic vulnerability for those that will see a decrease in population. However, for those countries that are projected to see a rise in population, this could mean more vulnerability. For example, Belize's population is expected to increase by 58% by 2100, likely due to migration from neighbouring countries Guatemala or Mexico.[78] With 60% of Belize covered in forests, while cities and towns make up 20% of the country's land, Belize could face population density issues with overcrowded urban centers, unsustainable land use planning (for example, rapidly deforesting areas to support urban growth) and higher rates of poverty which are inextricably linked to a host of other social issues such as political unrest or crime.[79] Population density (per sq.km) is an indicator of adaptive capacity, a component of "vulnerability", demonstrating the level of pressure that the human population is placing on ecosystems, as well as the ecosystems' ability to adapt to changes.[80] The higher the population density, the more vulnerable a country is to socioeconomic challenges. These socioeconomic factors compound the vulnerability arising from climate change. Therefore, for places like Belize that face increased projections of population, and where 50% of the population lie on the coast but also face high risks of sea level rise, adequate climate adaptation and investment planning is strongly recommended.

Population changes will directly impact land use planning and rates of urbanization. In return, these factors will lead to changes in the built environment, so that a country's adaptive capacity can aim to support changes in population density. However, if a country's land use planning is only focused on

[75] Stennett-Brown, R. K., Stephenson, T. S., & Taylor, M. A. (2019). Caribbean climate change vulnerability: Lessons from an aggregate index approach. PloS one, 14(7), e0219250. https://doi.org/10.1371/journal.pone.0219250
[76] Available at: https://www.cepal.org/en/pressreleases/latin-america-and-caribbean-reach-maximum-population-levels-2058
[77] Available at: https://www.pewresearch.org/fact-tank/2019/06/17/worlds-population-is-projected-to-nearly-stop-growing-by-the-end-of-the-century/
[78] Available at: https://repositorio.cepal.org/bitstream/handle/11362/45198/1/S1900739_mu.pdf
[79] Available at: https://worldpopulationreview.com/countries/cities/belize
[80] Available at: https://core.ac.uk/download/pdf/2767712.pdf

supporting a growing population (for example, in an effort to bolster economic growth), the built environment can place major stresses on the natural environment as well as socioeconomic components that have synergies with the built environment. For example, if population is expected to rise significantly within the next 20 years where younger generations are leaving rural farming areas to join urban centers, this can place more stress on cities and their underpinning services. Emergency service vehicles may have to deal with more road traffic, electricity shortages can cause interrupted services, water sewerage systems can be over-capacity and high pollution levels can lead to health concerns for individuals. Those who are already vulnerable, such as those in poverty or an aging population, are even more at-risk from a changing climate. In the case of Jamaica, which has seen rapid population growth and large rates of migration from agricultural areas to urban city centers from 34% in 1960 to 54% in 2011 (and projected to be 65% by 2050), unplanned growth has led to increased squatter occupation of available land – mainly in high-risk areas that are prone to landslides and flooding.[81] Therefore, sustainable planning and urban development can reduce socioeconomic vulnerability for future climate impacts.

In the Caribbean, over 50% of the population lives within a mile of the coast, in proximity to coastal areas that are protected by natural ecosystems such as coral reefs and mangroves (which can provide natural flood defenses against coastal flooding and inundation).[82] These natural ecosystems also underpin the revenue-generating tourism and recreation industries, such as scuba diving, and beachside resort vacations. When these natural ecosystems are under threat from physical climate change, it impacts the country's socioeconomic vulnerability. For example, Anguilla is one of the least densely population islands (approximately 153 people/sq. km) yet it is also upscale beach destination where 70% of the GDP is generated through the tourism industry. Given the island's physical vulnerability to hurricanes and other climate impacts, those tourism revenue dollars are at-risk in conjunction with sea-level rise destroying beachfront hotels and coral bleaching damaging reef ecosystems. This directly impacts the socioeconomic vulnerability of Anguillans to a changing climate.[83] Therefore, to address socioeconomic vulnerability that arises from a changing climate across the Caribbean, it is crucial to understand how individuals, communities and businesses benefit or have an enhanced quality of life from coastal and marine ecosystems and their services which are at-risk from climate hazards.

3.5 Limitations and data gaps

Indicator-based approach

By its nature, the indicator-based approach adopted in this report simplifies several complex and interacting parameters into a form that is more easily understood and has a greater utility as a planning and decision-making tool. Although the indicators chosen here were selected to consider both the harder and softer aspects of exposure, sensitivity, and adaptive capacity, this quantitative approach is limited because it will not be able to capture the full complexity and the various tangible and intangible aspects of vulnerability.

[81] Scott, O. and Zermoglio, F. (2018). Climate Vulnerability Assessment of Jamaica's Transport Sector. DO - 10.13140/RG.2.2.12889.21609
[82] Available at: https://iussp.org/sites/default/files/event_call_for_papers/IUSSP%20JAVIER%20LARGO%20PDF_0.pdf
[83] Available at: https://core.ac.uk/download/pdf/2767712.pdf

It is important to note that the exposure and vulnerability indicators included in this analysis differ from more conventional approaches towards quantifying these components of risk. For example, catastrophe risk modelling frameworks typically assume exposure to refer to the built environment, and will include physical assets according to various lines of business (e.g., residential, commercial, industrial). The most comprehensive database of this form of exposure across the BMCs is that developed by CCRIF, supported by EQECAT, KAC, and ERN-RED in successive iterations of CCRIF's modelling. Indicators drawn from this work could be incorporated into a future iteration of the approach presented here. Our current analysis focuses primarily on exposed populations, along with indicators to represent critical infrastructure and natural capital. The inability of standard catastrophe risk models to model hazard impacts on these diverse forms of exposure represents a substantial shortcoming.

In conventional risk modelling approaches, vulnerability is captured using damage curves that define the relationship between a given hazard intensity and the amount of damage that is sustained by a built structure of particular characteristics. The inclusion of the Building Quality Control Index captures this to some extent, although it does not discriminate by hazard or asset type. Rather, our treatment of vulnerability is much broader, considering the vulnerability of populations, with specific consideration towards the vulnerability of particular groups including women, the young and the elderly, as well as environmental vulnerability. A future iteration of our approach could consider hazard-specific vulnerability, and an expanded selection of vulnerable groups, though this would depend on the availability of consistent data across the region.

Data availability and gaps

A key limitation of this analysis is the absence of systematic and consistent data collection for exposure and vulnerability indicators across all BMCs, which made it necessary to accept indicators that were less exact or comprehensive than ideal or, in some cases, not consider indicators in the quantitative analysis. For example, from our literature review and discussions with key experts poverty rate was identified as an important indicator for a vulnerability analysis. Figure 15 shows the data that we have been able to collect for this metric from international sources (e.g. World Bank, UN) and from CDB's Recovery Duration Adjustment Team, who in turn collected data from BMC's Statistical Offices. With the exception of Jamaica, most BMCs have only one or two data points over the past 23-years (2000-2022) and only six BMCs have recorded poverty rates since 2011. In part, this lack of systematic data may be because the statistical capacity of many BMCs is low and has fallen in recent years, resulting in less periodic and timely updates to key indicators within the national statistics system (Table 17).

This lack of systematic and consistent data collection is particularly acute for data that is sex-disaggregated, gender-sensitive, or linked to other marginalised groups. It is important to note that these gender data gaps are not unique to the Caribbean. A 2019 study produced by UN Women's Disaster Risk Reduction and Resilience Team found that at the global level, "data gaps excluding marginalised groups were apparent in all data sets, including at census level, meaning marginalised groups were often invisible in analysis, policy, and practice".[84] This is also reflected by gaps in Caribbean DRM and climate change policies, with Grenada's Drought Management Plan from 2019 specifically mentioning the unfortunate lack of gender-disaggregated data for disaster risks in Grenada as a key barrier to

[84] Brown, S., Budimir, M., Upadhyay Crawford, S., Clements, R., and Sneddon, A., (2019) Gender and Age Inequality of Disaster Risk: Research Paper, UNICEF and UN Women

implementing the Government's Gender Equity Policy and Action Plan (GEPAP) 2014 – 2024 in the context of drought management.[85]

Notable gaps in data availability – both gender-specific and in general - are:

- Literacy rates, disaggregated by sex;
- Poverty rates, disaggregated by age and sex;
- Access to finance/financial services, disaggregated by sex and specifically information on, for example, women's uptake of bank accounts and access to credit and insurance;
- Sex-disaggregated data on access to social protection mechanisms and paid and unpaid domestic work; and
- Women in decision making positions, specifically in relation to DRM and climate policy making as well as in DRM implementation, monitoring and evaluation.

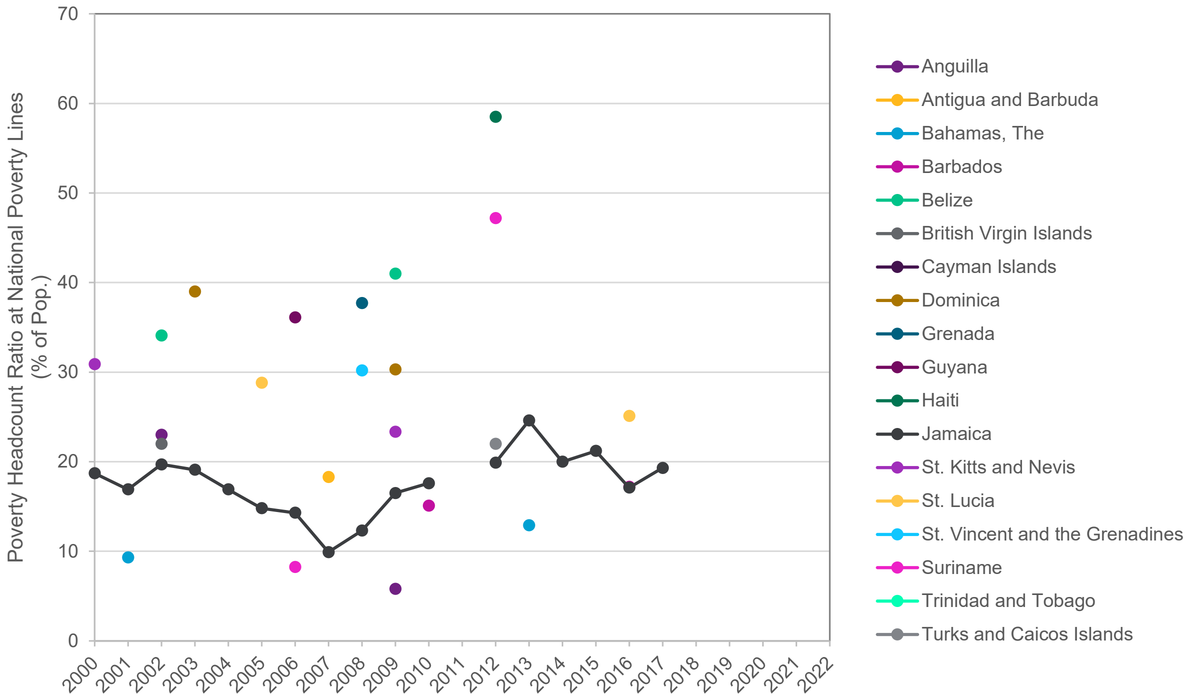


Figure 15 Poverty Headcount Ratio at National Poverty Lines (% of population) data available between 2000-2022 for BMCs. Source: CDB's Recovery Duration Adjustment Team, based on World Bank data and CDB sources.

[85] Available at: https://knowledge.unccd.int/sites/default/files/country_profile_documents/1%2520FINAL_NDP_Grenada.pdf

Country	2016	2017	2018	2019	2020
Antigua and Barbuda	57.78	54.44	43.33	47.78	44.44
Barbados	NULL	NULL	NULL	NULL	NULL
Belize	62.22	62.22	63.33	63.33	58.89
British Virgin Islands	NULL	NULL	NULL	NULL	NULL
Cayman Islands	NULL	NULL	NULL	NULL	NULL
Dominica	57.78	57.78	51.11	50.00	46.67
Grenada	51.11	53.33	56.67	57.78	54.44
Guyana	57.78	55.56	55.56	50.00	45.56
Haiti	38.89	36.67	50.00	46.67	53.33
Jamaica	77.78	71.11	62.22	61.11	54.44
Saint Kitts and Nevis	53.33	50.00	46.67	44.44	39.44
Saint Lucia	64.44	57.78	61.11	58.89	56.67
Saint Vincent and the Grenadines	60.00	56.67	53.33	60.00	50.00
Suriname	65.56	72.22	71.11	71.11	57.78
Bahamas, The	NULL	NULL	NULL	NULL	NULL
Trinidad and Tobago	61.11	46.67	47.78	47.78	47.78
Turks and Caicos Islands	NULL	NULL	NULL	NULL	NULL

Table 17 Statistical capacity indicator for BMCs between 2016 and 2020 of a scale of 0 (worst) – 100 (best). The statistical capacity indicator is a composite score assessing the capacity of a country's statistical system. It is based on a diagnostic framework assessing the following areas: methodology; data sources; and periodicity and timeliness. *Source: World Bank.*

One key recommendation from this report is establishing the need for routine, regionally consistent data collection protocols with specific attention towards gender-specific indicators as well as the disaggregation of more established indicators along gender lines. Establishing this as a priority across the BMCs would enable future analyses to include a greater number of such indicators, and ensure that the most vulnerable groups are represented in regional vulnerability assessments. Although often not yet requested for national policy-making processes, in some cases, such data may already be partially available through countries' Central Statistical Offices as mentioned by CDB (2016).[86]

The above notwithstanding, it is important to note that a recent desk review by the World Bank offers important additional insight for some BMCs.[87] Paying close attention to these characteristics is key to ensuring more gender-sensitive DRM and disaster risk finance approaches and include complementary information such as:

[86] https://www.caribank.org/sites/default/files/publication-resources/SynthesisReport_CountryGenderAssessment.pdf
[87] https://openknowledge.worldbank.org/bitstream/handle/10986/35215/Gender-Responsive-Disaster-Preparedness-and-Recovery-in-the-Caribbean-Desk-Review.pdf?sequence=1&isAllowed=y

- In 2019, 30 percent of the employed women in Belize, Guyana, Jamaica, and Saint Lucia held what is called vulnerable employment, defined as "the sum of own-account workers who hold self-employed jobs and are contributory family workers". As a such employed workforce is significantly less likely to contribute to pension or social insurance mechanisms, their access to social protection schemes and safety nets is limited to non-existing. Understanding this when assessing BMCs' gender-related sensitivity and adaptive capacity to external shocks will be essential for developing gender-sensitive DRF instruments, such as, for example, adaptive social protection as the instrument's delivery mechanism.

- The lack of gender-based violence (GBV) shelter policies can create inherently unsafe environments in disaster settings and reduce women's and girls' adaptive capacity. As the post-disaster needs assessment in Dominica in 2017 or Saint Lucia's gender assessment in 2019 highlight, women and children were at particular GBV risk due to insufficient integration of gender-related considerations into shelter design. Considering these circumstances in the context of gender-sensitive DRF instruments could mean making the access and utilisation of disaster response funds conditional on addressing gender-related risks in relief efforts.

Spatial resolution

The assessment of exposure and vulnerability presented above focuses on the national level. This helps to build a regional view of risk across the BMCs, and allows for relative comparisons. This approach is appropriate to guide regional-level prioritization, and to some extent planning and decision-making. However, it does obscure more nuanced patterns of vulnerability and exposure that occur at the local scale.

In theory, the same set of exposure and vulnerability indicators can be applied to geographical units regardless of their size, providing that relevant, reliable, and complete data is available. To conduct a sub-national exposure and vulnerability assessment, more granular spatial exposure data sets and associated vulnerability scores and relations will be needed. Table 20 in Section 6.3 provides examples of high-resolution (<1 km) exposure datasets that could be used to interrogate exposure and vulnerability at the sub-national scale.

4 Overview of risk management approaches

Effective and cost-efficient risk management relies on the recognition that different levels of risk (as defined by frequency / severity) demand different management approaches. For extremely rare, high-impact events, it may not be feasible or desireable to actively manage the associated risk. This arises because the considerable cost associated with managing such risks cannot be justified given the very low chance of that risk materialising in a timeframe that can be reasonably considered.

For those risks that can be managed, initially it is generally preferable to focus on risk reduction / mitigation, guided by cost-benefit analysis, since this reduces the overall risk to be managed. Of those risks that cannot be reduced through mitigation activities, two options remain, risk retention, and risk transfer (Figure 16).

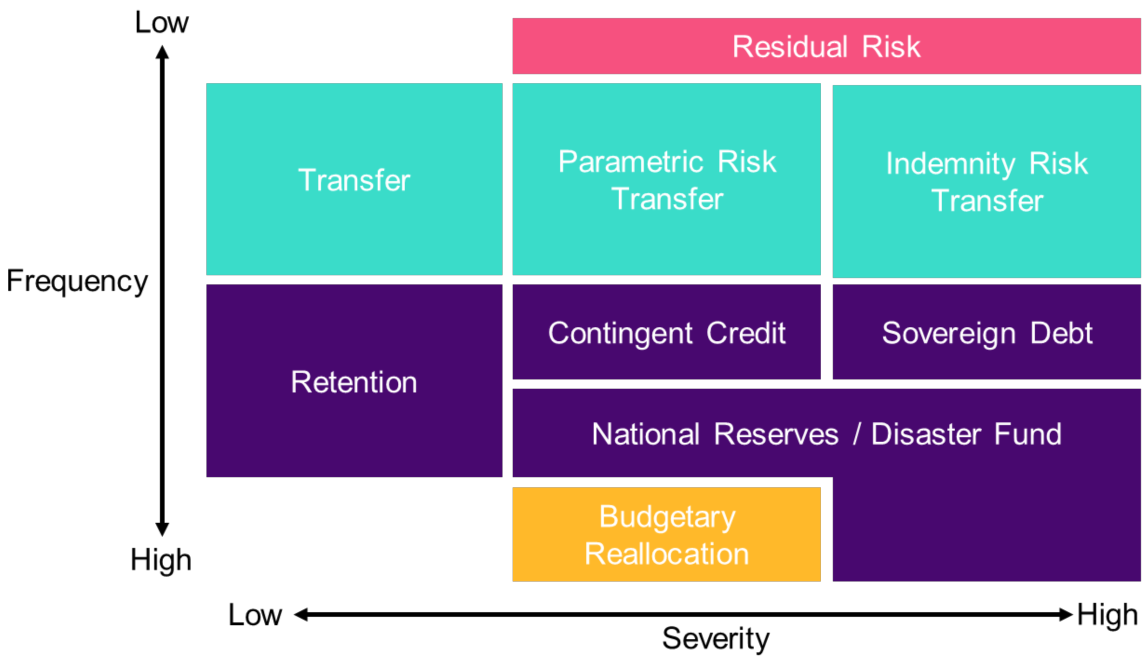


Figure 16 Spectrum of financial instruments used for disaster risk management and planned disaster response. Adapted from UN-ESCAP (2018) and CCRIF.[88]

Risks that are characterised by relatively high frequencies are, by nature, less severe and so can likely be managed through budget reallocations and sovereign reserves. That said, reliance on these instruments presents an opportunity cost, since funds must be diverted from other policy objectives in areas such as health, education, environmental sustainabilty among others, and can impact on overall development outcomes. Additionally funds are likely to be limited in several BMCs which have

[88] UN-ESCAP. 2018. Opportunities for Regional Cooperation in Disaster Risk Financing. 70pp.

considerable levels of sovereign debt. Traditional risk transfer is typically an expensive option to manage high frequency, low severity events.

Instead, risk transfer is generally most cost-effective for managing less frequent, high severity events. The selection of risk transfer instrument depends on the intended use for pay-outs received in the case of a qualifying event. If funds are required for longer-term reconstruction and recovery, indemnity risk transfer will be valuable since it ensures that the pay-out received reflects the actual damage sustained. If funds are required for immediate post-event response and recovery actions, or for more poorly-quantified risks, then parametric risk transfer is likely more appropriate since it can allow for pay-outs within a week of the event itself and can cover a range of different losses from the same event.

Figure 17 provides a conceptual summary of the return period thresholds for which different risk management approaches are likely to be most appropriate. The figure shows that different return periods should be targeted depending on the hazard. This is largely a function of the frequency / magnitude profiles that characterise each hazard. For example, while a 1:250-year tropical cyclone wind event is very unlikely and so does not need to be an active target for management, for earthquake shaking, risk transfer only becomes cost-effective at these higher return periods.

	Return Period								
	2	**5**	**10**	**25**	**50**	**100**	**250**	**500**	**1000**
Tropical Cyclone Wind			X	X					
Earthquake Shaking				X	X	X			
Riverine Inundation		X	X	X					
Coastal Inundation			X	X	X				

	Budget reallocation	**Sovereign reserves / contingent credit**	**Risk transfer**	**Residual risk**
Indicative impact level (% GDP value of loss and damage)	**<5%**	**<10%**	**10% - 50%**	**>50%**

Figure 17 Illustrative return period thresholds for managing risk through reallocation (green), sovereign reserves / contingent credit (blue), and traditional insurance (pink). Unmanaged residual risk is also indicated (grey). 'X' denotes return periods at which parametric forms of risk transfer may be considered.

Regardless of the financial instrument used, it is important that the needs of disadvantaged groups - including women and girls who are at risk because of gender practices, the very old and the very young, those with certain diseases or disabilities and people of a particular sexual orientation - are integrated into risk management and reduction plans and procedures from both perspectives of persons as beneficiaries and as decision-makers.

It is important to note that Figure 17 presents a generic case that does not take into account country or asset-specific context which may alter the return period thresholds that are appropriate to different management approaches. On a case-by-case basis, these contextual factors can be taken into account, and used to provide a quantitative assessment of risks that can be actively managed (as well as the unmanaged residual risk). For example, for any given government infrastructure project, the return period intensity of tropical cyclone wind risk that can be sustained will differ depending a wide range of characteristics, including but not limited to the type of infrastructure (e.g., drainage is likely less susceptible than electricity transmission and distribution networks), the quality of building materials, and whether building codes are enforced. Furthermore, characteristics that make infrastructure resilient to tropical cyclone winds may not afford protection to earthquake shaking, or inundation. Another example is the dependable size of a national contingency reserve; sustaining only a small reserve and not having easy access to contingent credit might require risk transfer to be deployed at lower return periods.

The case study below demonstrates how a structured approach to determining resilience thresholds can be implemented at the national and sub-national scale.

4.1 Coalition for Climate Resilient Investment in Jamaica

Damage to public assets is the largest disaster related liability of central governments.[89] Public assets typically include buildings (schools, hospitals, government buildings), infrastructure (roads, bridges, water and power), and critical facilities (wastewater treatment plants, power generation). Since governments hold the ultimate responsibility for these assets, they represent a considerable source of contingent liability in the context of environmental disasters. Furthermore, the contribution of such assets to country balance sheets often goes unreported,[90] leading to an underestimation of damages when disasters occur.[91] Protection of public assets from natural hazards is crucial given that such assets underpin economic activity and social service provision and include crucial components of post-disaster recovery efforts. This section illustrates a structured methodology that has been developed by the Coalition for Climate Resilience Investment (CCRI), firstly to quantify risk to critical infrastructure, and then to use this information to identify and implement climate resilient investment opportunities.

The CCRI is a group of over 120 institutions, representing USD 25 trillion of financial assets, formed with the aim of engendering climate resilient national planning and asset-level investment. The CCRI is guided by the principle that by "pricing climate risk in financial decision-making, investors will be encouraged to build infrastructure that is more resilient and capable of withstanding the present and

[89] OECD and World Bank. 2018. Boosting Fiscal Resilience: Managing Disaster Related Contingent Liabilities in Public Finance Frameworks. Technical Contribution to the APEC Finance Minister' Process. 204pp.
[90] IMF. 2018. The Wealth of Nations: Governments Can Better Manage What They Own and Owe. Accessible at: https://blogs.imf.org/2018/10/09/the-wealth-of-nations-governments-can-better-manage-what-they-own-and-owe/
[91] World Bank. 2019. Boosting Financial Resilience to Disaster Shocks: Good Practices and New Frontiers. 56pp.

future impacts of climate change…"[92]. The CCRI is divided into three Technical Working Groups, each dedicated towards furthering a specific element of climate resilience (Figure 18).

Figure 18 Coalition for Climate Resilient Investment (CCRI) summary graphic. Reproduced with permission.

The Systemic Resilience Technical Working Group, which aims to support governments to assess and manage systemic exposure to physical climate risks, is particularly relevant when thinking about disaster risk management approaches as appropriate to the BMCs. The three key outcomes of this working group are:

1. *National Investment Prioritisation Tool* – designed to identify hotspots of risk across infrastructure networks. This information is valuable to help governments protect and enhance assets that are of greatest value. The tool is geospatial and tailored to specific country contexts.

2. *Systemic Resilience Metrics* – used to demonstrate how properly integrating physical climate risk into decision making can impact an entity, government, or city's macro- and socio-economic risk.

[92] Coalition for Climate Resilience Investment. Accessible at: https://resilientinvestment.org/

3. *Pilot projects* – identifying and implementing outcomes 1. and 2. in specific country contexts. This includes attention towards both existing projects and project investment pipelines.

The method deployed through the National Investment Prioritisation Tool demonstrates how the national-scale risk audit presented in this report can be further refined to provide sub-national insights. In collaboration with the Governments of Jamaica and the UK, as well as Green Climate Fund (GCF), the CCRI has deployed a systemic resilience assessment tool in Jamaica. This tool will support the Government of Jamaica to understand and integrate physical climate risk in the prioritisation of resilient infrastructure investment. Since 2004, infrastructure vulnerability has been recognised, as storms contributed to 15-90% of total damage in Jamaica. The tool provides a visual element to enable the Jamaican government to visualise hotspots of high levels of economic and social value at risk, in relevant time horizons. This will benefit the government by the prioritisation of funding and more efficient allocation of public and private capital towards resilience projects. In addition, such analysis will support and incentivise the development of a resilient infrastructure project pipeline. Where previously the lack of incentive to invest in risk resilience will be overcome as the long-term financial benefit to both the government and the investor is presented and understood cohesively (Box 2).

Key lessons learned from the Jamaica case study, which should be considered when applying this approach elsewhere across the BMCs, include:

- The Tool must be customised in conjunction with the government needs and on sufficient scale to attract external investors;
- Relatedly, the Tool must be integrated to the planning and investments process of the country in question to ensure that it is used actively;
- The country must have sufficient availability of data; and
- Currently the model is static; future versions should be sufficiently flexible to allow input data to be updated as new data is acquired.

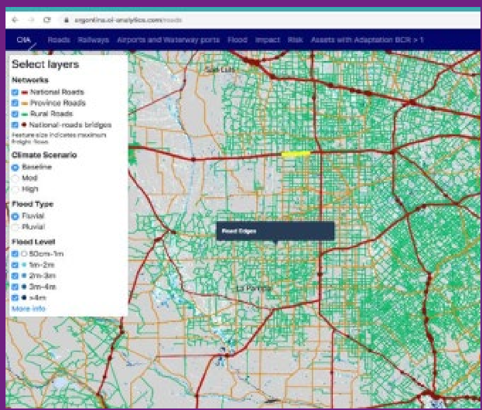
Box 2: The National Investment Prioritisation Tool, applied to Jamaica.

National Investment Prioritisation Tool

This box provides more detail on the systematic resilience assessment tool.

The systematic resilience tool is being piloted in Jamaica; however, the developed methodology is prepared to be generalised to five other jurisdictions. The first stage of the tool involves **georeferencing all assets** contained within a given network and assessing their exposure to selected hazards. The second stage builds on the initial stage by **assessing the interdependencies** between all assets within the given networks. The third stage **overlays the economic and social** flows that rely on the given infrastructure network. Finally, a visual and dynamic representation of exposure in a given network is produced and a list of priorities is established.

1. Input
User adjusts key parameters for the visualisation and prioritisation



3. Output
Listing the top 25 geolocations based on their concentration of economic and social value at risk

Lat	Long	Sector	Hazard	National Value at Risk
11229	-1.21344	Transport	TC	120
11549	-1.43344	Water	DR	143
11869	-1.65344	Energy	SLR	166
12189	-1.87344	Energy	TC	189
12509	-2.09344	Water	DR	212
12829	-2.31344	Transport	SLR	235
13149	-2.53344	Energy	TC	258
13469	-2.75344	Water	DR	281
13789	-2.97344	Transport	TC	304
14109	-3.19344	Energy	SLR	327
14429	-3.41344	Transport	FL	350
14749	-3.63344	Transport	SLR	373
15069	-3.85344	Energy	FL	396
15389	-4.07344	Transport	DR	419
15709	-4.29344	Energy	TC	442
16029	-4.51344	Energy	SLR	465
16349	-4.73344	Water	DR	488
16669	-4.95344	Transport	FL	511
16989	-5.17344	Energy	SLR	534
17309	-5.39344	Water	SLR	557
17629	-5.61344	Energy	TC	580
17949	-5.83344	Transport	DR	603
18269	-6.05344	Water	TC	626
18589	-6.27344	Transport	SLR	649
18909	-6.49344	Transport	DR	672

The results comprise of a direct damage estimate and an indirect economic loss estimation of GDP disruptions due to asset failures and service disruption. The government can then **utilise** this analysis to provide an **incentive** for public and private investors to invest in projects that improve risk resilience.

5 Regional view of disaster risk across BMCs

This section summarises the hazard, exposure, and vulnerability analysis to provide a regional view of disaster risk across the BMCs. Figure 19 provides a simple, qualitative, classification of the BMCs into severe, high, and moderate / low groupings by hazard. This classification is based on the probabilistic analysis undertaken in this study (for earthquake shaking and tropical cyclone wind), the SPHERA probabilistic modelling (that underpins the CCRIF Risk Profiles), and a review of historical hazard events across the region (see Table 2).

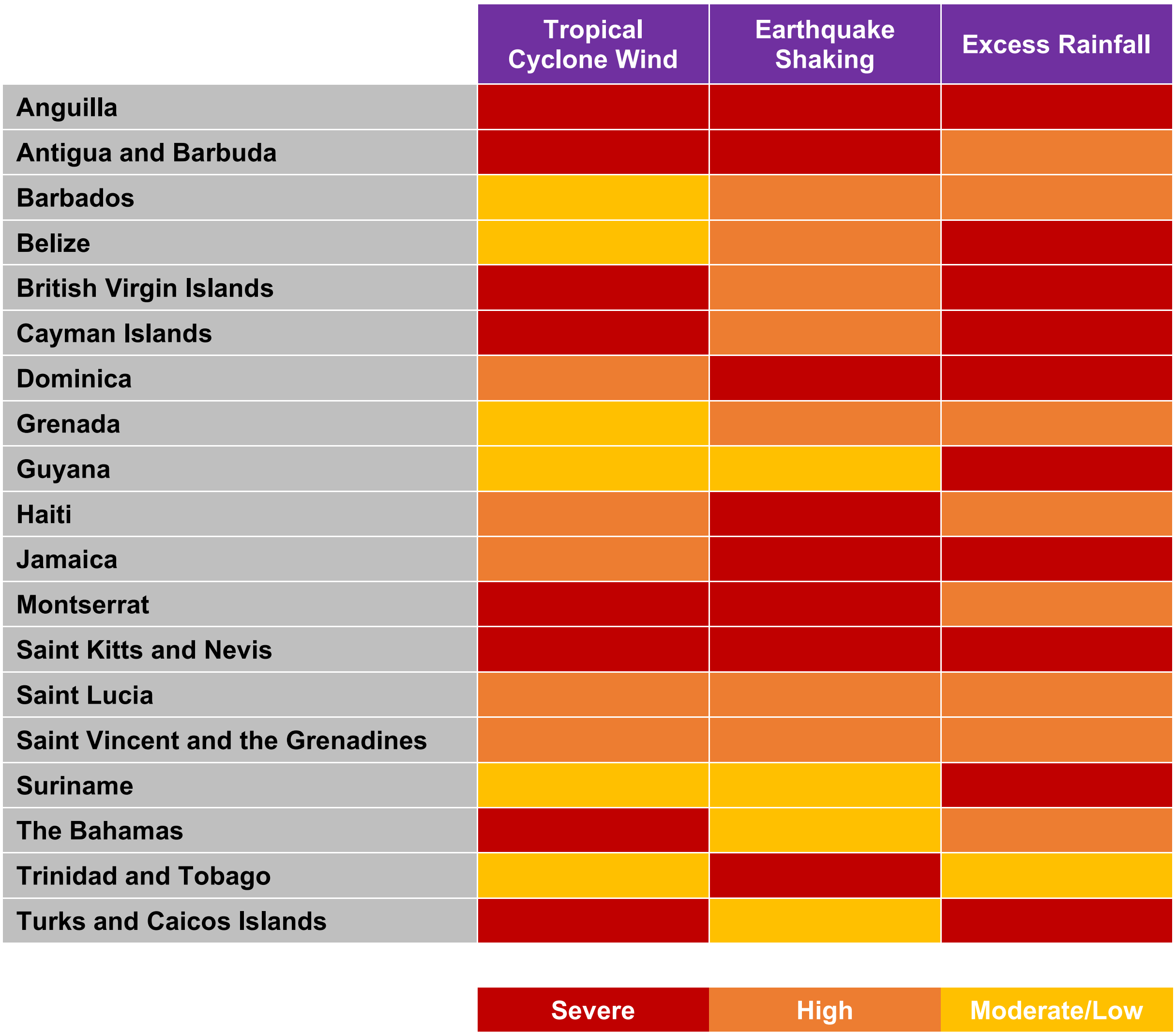


Figure 19 Summary of hazard exposure across the BMCs.

While Figure 19 provides an overview of hazard by country, in reality, each country faces different hazards, of varying severities, making it difficult to determine a ranking based on hazard alone. Rather, this analysis can be used to direct more detailed national and sub-national hazard modelling studies towards the hazard that impact relatively higher proportions of the population.

Table 18 presents normalised, aggregated exposure and vulnerability scores for each of the BMCs where sufficient vulnerability data was available (see Section 3.3). Haiti emerges as having the highest exposure / vulnerability combination. A number of countries score highly in terms of exposure but with relatively lower vulnerability scores (e.g., Barbados and The Bahamas). Alongside Haiti, Guyana, Belize, and Suriname score relatively higher on vulnerability, relative to exposure.

	Exposure		Vulnerability	
	Norm.	Rank	Norm.	Rank
Antigua & Barbuda	0.38	4	0.31	13
Barbados	0.35	8	0.39	11
Belize	0.14	13	0.92	4
Dominica	0.37	5	0.57	6
Grenada	0.30	10	0.55	7
Guyana	0.10	14	1.16	2
Haiti	0.43	2	4.14	1
Jamaica	0.35	6	0.32	12
Saint Kitts & Nevis	0.39	3	0.44	10
Saint Lucia	0.22	12	0.45	9
Saint Vincent & the Grenadines	0.35	7	0.57	5
Suriname	0.29	11	0.97	3
The Bahamas	0.63	1	0.21	14
Trinidad & Tobago	0.33	9	0.49	8

Table 18 Summary of exposure and vulnerability across the BMCs.

A key outcome from this study is the need to prioritise the collection of key disaster risk indicators in countries where this information is currently lacking. Without such a baseline it will be difficult to assess progress towards addressing disaster risk in these countries. For instance, Anguilla and Montserrat score highly in terms of hazard but it was not possible to assess exposure and vulnerability quantitatively in this study due to lacking indicator availability. This also applies to gender-related indicators specifically, where a lack of data availability makes generating a regional view of gender-related vulnerability / risk exposure / resilience needs challenging. The approaches developed here are flexible in that they can be updated as new information is made available and they can be enhanced through the use of higher-resolution and sub-national datasets.

The regional risk audit presented here provides a foundation for subsequent tasks by identifying the drivers of hazard, exposure, and vulnerability to disaster risk across the region. Figure 20 provides a qualitative summary of this information. This analysis will be used as a springboard for discussion during the stakeholder consultations, and to inform the selection of appropriate disaster risk financing instruments in subsequent phases of the project.

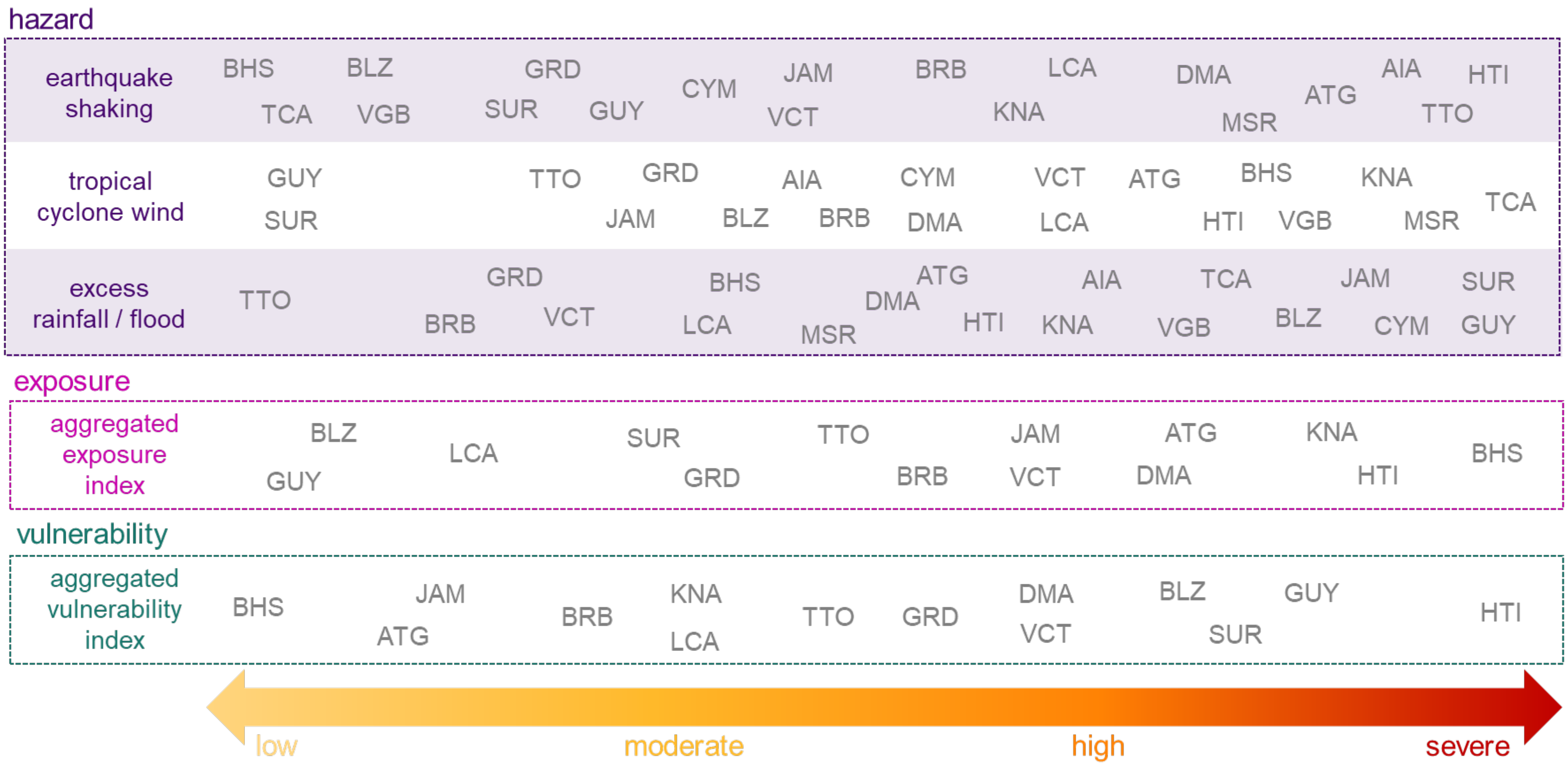


Figure 20 Regional view of disaster risk across the BMCs. ISO 3166-3 names are used, Anguilla (AIA), Antigua and Barbuda (ATG), Barbados (BRB), Belize (BLZ), British Virgin Islands (VGB), Cayman Islands (CYM), Dominica (DMA), Grenada (GRD), Guyana (GUY), Haiti (HTI), Jamaica (JAM), Montserrat (MSR), Saint Kitts and Nevis (KNA), Saint Lucia (LCA), Saint Vincent and the Grenadines (VCT), Suriname (SUR), the Bahamas (BHS), Trinidad and Tobago (TTO), and Turks and Caicos Islands (TCA).

6 Appendix

6.1 Review of hazard modelling and risk profiling studies

Table 19 provides details of hazard modelling studies conducted across the Caribbean.

Hazard modelling platforms / projects	Hazard(s)	Description	Vintage	Spatial Scale	Countries	Source
Caribbean Institute for Meteorology and Hydrology (CIMH) data centre	Various hydrometeorological variables	The CIMH maintains an archive of meteorological and hydrological data from member countries of the CMO. The archive consists of hourly synoptic and daily climatological data collected at airport stations operated by the meteorological services; daily climatological data from independent climatological/agrometeorological stations; daily and monthly rainfall, stream flow, and stage data from hydrological services and water agencies. The data records at the CIMH date back to about 1970 but some earlier records, particularly rainfall, are also available. The original records are in paper form, but the vast majority are stored in digital, computer database files. The data are archived in special meteorological and hydrological databases which allow easy access to the data.	1970 – present	National, Sub-national	Antigua and Barbuda, Barbados, Belize, Cayman Islands, Dominica, Grenada, Guyana, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Islands	http://www.cimh.edu.bb/?p=home
OAS Caribbean Disaster Mitigation Project (CDMP)	Earthquake, hurricane (inc. surge), landslide	A joint effort of the Organization of American States (OAS) and the US Agency for International Development (USAID), with the aim of establishing sustainable public/private disaster mitigation mechanisms that measurably lessen loss of life, reduce potential damage, and shorten the disaster recovery period.	1999	National	Antigua and Barbuda, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Trinidad and Tobago	http://www.oas.org/cdmp/

OAS Post-Georges Disaster Mitigation Project (PGDM)	Hurricane, drought, flooding, erosion, volcanic	In response to the damages from Hurricane Georges, the US Agency for International Development-Jamaica/Caribbean Regional Program (USAID-J/CAR), established a program entitled Hurricane Georges Reconstruction and Recovery in the Eastern Caribbean, targeting Antigua and Barbuda and Saint Kitts and Nevis. The Organization of American States' Unit for Sustainable Development and Environment (OAS/USDE) implemented the disaster mitigation capacity building component for USAID-J/CAR, under the project Post-Georges Disaster Mitigation (PGDM). [See PGDM background information for further details.] The PGDM included four primary objectives: 1. develop national hazard mitigation policies and plans, 2. strengthen building practices, 3. strengthen national emergency shelter policies and programs, 4. support public information programs on hazard mitigation.	1999	National, Sub-national	Antigua and Barbuda, Saint Kitts and Nevis	http://www.oas.org/pgdm/
Various iterations for CUBiC wind loading guidance	Hurricane	Wind code evaluation guidance for CARICOM Caribbean Islands.	2001	National	Antigua and Barbuda, Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago	https://www.eird.org/cd/acs/English/CodeEval/EngSpeak/Wind/CUBiCwce.pdf
CARIBSAVE Climate Change Risk Atlas (CCCRA)	Climate-related risks	The CARIBSAVE Climate Change Risk Atlas (CCCRA) Phase I, funded by the UK Department for International Development (DFID) and the Australian Agency for International Development (AusAID), was conducted from 2009 – 2011 and successfully used evidence-based, inter-sectoral approaches to examine climate change risks, vulnerabilities, and adaptive capacities; and develop pragmatic response strategies to reduce vulnerability and enhance resilience in 15 countries across the Caribbean	2011		Anguilla, Antigua and Barbuda, Barbados, Belize, Dominica, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Turks and Caicos Islands	https://www.caribbeanclimate.bz/blog/2010/02/11/2009-2011-the-caribsave-climate-change-risk-atlas-cccra/

Global Assessment of Report on Disaster Risk Reduction 2015 (GAR15)	Earthquake. Flood, Wind	The 2015 Global Assessment Report on Disaster Risk Reduction (GAR15), Making Development Sustainable: The Future of Disaster Risk Management, is the fourth in the series coordinated by the United Nations Office for Disaster Risk Reduction (UNISDR) in the context of the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters (HFA).	2015	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.preventionweb.net/english/hyogo/gar/2015/en/home/index.html , https://www.preventionweb.net/english/hyogo/gar/2015/en/home/index.html , , https://www.preventionweb.net/english/hyogo/gar/2015/en/home/index.html
World Bank Country Risk Profiles for Latin America and the Caribbean	Earthquake, flood, wind	Country risk profiles developed by the World Bank and the Disaster-Resilience Analytics & Solutions (DRAS) team.	2015-2018	National	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://riskviewer.worldbank.org/
Global Earthquake Model Foundation (GEM) Caribbean and Central American Hazard Mosaic	Earthquake	Assisted by an initiative of the OECD's Global Science Forum, GEM was formed in 2009 as a non-profit foundation, funded through a public-private sponsorship with the vision to create a world that is resilient to earthquakes. GEM's mission is to become one of the world's most complete sources of risk resources and a globally accepted standard for seismic risk assessment; and to ensure that its products are applied in earthquake risk management worldwide.	2019	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://hazard.openquake.org/gem/models/CCA/
World Resources Institute (WRI) Aqueduct Floods	Flood	WRI is an internationally recognised research organization focusing on natural resource availability, quality and impacts. WRI produces maps, charts, data sets, infographics, and other visual resources as part of their commitment to turn "information into action."	2020	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.wri.org/research/aqueduct-floods-methodology

Inter-American Development Bank (IDB) Risk Profiles	Earthquake, flood, wind	Selected in-depth risk profiles developed by the IDB.	2020	National, Sub-national	Jamaica, The Bahamas	
Jeremy Benn Associates (JBA)	Flood	JBA are a flood risk modelling company that specialises in catastrophe risk modelling, analytics, consultancy, and event response.	2020	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.jbarisk.com/flood-services/catastrophe-models/flood-models/global-flood-model/
WHO UNFCCC Health and Climate Change Country Profiles	Climate-related risks	"The Health and Climate Change Country Profile Project forms the foundation of WHO's monitoring of national and global progress on health and climate change. Working in collaboration with national health authorities and health stakeholders, the Project aims to: Increase awareness of the health impacts of climate change; Support evidence-based decision making to strengthen the resilience of health systems; Support health involvement in national and international climate processes such as the United Nations Framework Convention on Climate Change (UNFCCC); and Promote actions that improve health while reducing greenhouse gas emissions."	2020-2021	National	Antigua and Barbuda, Dominica, Grenada, Guyana, Jamaica, Saint Lucia, Suriname, The Bahamas, Trinidad and Tobago,	https://www.who.int/activities/monitoring-health-impacts-of-climate-change-and-national-progress
Caribbean Catastrophe Risk Insurance Facility (CCRIF SPC)	Hurricane, excess rain, earthquake	CCRIF prepares country risk profiles for each member country for tropical cyclones, earthquakes and excess rainfall. The profiles provide an outline of the hazard characteristics and risks for the country as well as economic loss information used by CCRIF catastrophe models and include information about the models that underpin the associated products. The profiles have been designed to provide this information in a simple, accurate and robust manner covering the demographic, geological and economic characteristics of their territories, whilst assessing the impacts of historical events that may have caused damage to infrastructure, population and the economy. The profiles act as the basis for pricing for countries' CCRIF policies	2021	National	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.ccrif.org/ccrifs-country-risk-profiles

CoreLogic	Earthquake, Hurricanes	CoreLogic specialises in financial, property, and consumer information, analytics, and business intelligence. The company analyses information assets and data to provide clients with analytics and customised data services. This includes a number of commercial catastrophe risk models.	2022	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.corelogic.com/protect/catastrophe-risk-management-solutions/ , https://www.corelogic.com/protect/catastrophe-risk-management-solutions/
AIR (Verisk)	Earthquake, Hurricanes	Verisk is a data management and predictive modelling firm. Previously known as AIR Worldwide, they have a number of catastrophe risk models covering various perils.	2022	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.air-worldwide.com/models/Earthquake/, https://www.air-worldwide.com/models/tropical-cyclone/
RMS	Earthquake, hurricanes	RMS is a risk management company that specialises in catastrophe risk modelling and advanced risk analytics.	2022	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.rms.com/models/earthquake, https://www.rms.com/models/cyclone-hurricane-typhoon
Applied Research Associates (ARA)	Hurricanes	ARA is a technology and solutions company. They developed the HurLoss Hurricane Catastrophe Model. The model includes a physical hurricane hazard component (for wind and surge), as well as an impact module which focuses on modelling physical damage and economic loss.	2022	National, sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.ara.com/hurloss/
Kinetic Analysis Corporation (KAC)	Hurricanes (including surge and rainfall)	Kinetic Analysis Corporation provides a global, multi-model, multi-hazard view of deterministic and probabilistic hazard, damage and loss data. Multi-model, deterministic data are available in near real-time for ongoing events, as well as for historical or hypothetical scenarios.	2022	National, sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.kinanco.com/

MeteoFrance Public Data Portal	Various hydrometeorological variables	MeteoFrance is the national hydrometeorological monitoring agency for France and overseas territories. It provides various climate and weather-related services including collecting, storing, and analyzing numerous atmospheric and ocean variables	Variable	National, Sub-national	Guyana	https://donneespubliques.meteofrance.fr/
Caribbean Disaster Emergency Management Agency (CDEMA) - Caribbean Risk Information System (CRIS)	Assets and critical infrastructure	CRIS is a multi-faceted virtual platform that hosts risk management data and information accessible to stakeholders to facilitate analysis, research, greater awareness of risk management and climate change adaptation in the region. The CRIS contributes to the region's sustainable development efforts by enhancing and strengthening disaster risk and climate change information sharing to drive evidence-based decision-making processes at all levels.	Various	National, Sub-national	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://cdema.org/cris/
Inter-American Development Bank (IDB) Riskmonitor Platform	Landslide, coastal erosion, flood, drought, earthquake, tropical storm, tsunami, volcanic, fire, hurricane, gale-force winds, and storm.	Country risk profiles developed by the IDB. The Riskmonitor platform provides country-level risk profile for various hazard including tabular and GIS data.	Various	National, Sub-national	Barbados, Guyana, Haiti, Jamaica, Suriname, The Bahamas, Trinidad and Tobago	https://riskmonitor.iadb.org/en
University of West Indies Climate Studies Group Mona Country Risk Profiles	Various	The Climate Studies Group Mona (CSGM) was formed in 1994 to explore Caribbean climate and the ocean and atmospheric influences that modulate how the climate manifests. The CSGM has developed statistical models using historical weather data to represent the patterns observed. The work has been expanded to examine historical and future climate change and the potential impacts on the lives and livelihoods of the Caribbean.	Unknown	National	Anguilla, Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, The Bahamas, Trinidad and Tobago, Turks and Caicos Islands	https://www.mona.uwi.edu/cardin/country-profiles
University of West Indies Seismic Research Centre	Earthquake, volcano, tsunami	Through monitoring, research and outreach, The UWI Seismic Research Centre promotes the safety of citizens against the impact of earthquakes, volcanoes and tsunamis in the English-speaking Eastern Caribbean.	Various	National, sub-national	Anguilla, Antigua and Barbuda, Barbados, Dominica, Montserrat, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago	https://uwiseismic.com/

Table 19 Hazard modelling platforms and projects across the Caribbean.

6.2 Review of exposure datasets

Table 20 presents high resolution exposure datasets available across the Caribbean.

Critical asset type	Description	Source	Methodology	Coverage	Resolution	Information / Attributes	Record Length
Key healthcare facilities	Doctors, clinics, hospitals, pharmacies, laboratories	The Global Healthsites Mapping Project. https://healthsites.io/	healthsite.io captures and validates information on health facilities through collaborations with OpenStreetMap, users and trusted partners. Data is created in three main ways i) importing existing open datasets of health facilities, ii) through surveying the site directly, and iii) crowdsourcing.	Regional	Point data	Name of facility, lon & lat, type, physical address, contact number, nature of the facility, scope of service, opening hours, inpatient service, inpatient service, ancillary services, activities, staff and ownership	N/A
Population	Population counts	WorldPop. https://www.worldpop.org	Various gridded population count datasets are produced by WorldPop, each with a different method and end application. In general, datasets are either "top-down" or "bottom-up" and either "constrained" or "unconstrained". **"Top-down" methodology.** A global database of administration unit-based census and projection counts for each year 2000-2020 is taken and disaggregated for either i) each 100x100m or 1x1km grid cell on the planet (top-down unconstrained) or ii) each 100x100m or 1x1km grid cell classified as settled by humans (top-down constrained). **"Bottom-up" methodology.** Sample data from recent survey datasets are used alongside geospatial datasets to build a statistical model to estimate population numbers and age/sex breakdowns in unsampled locations, together with measurements of uncertainty.	Global	100m or 1km (varies by dataset)	Estimated population count per grid-cell.	2000-2020 (unconstrained) 2020 only (constrained)

Population	Population counts, disaggregated by age-sex	WorldPop. https://www.worldpop.org/	Both top-downed 'unconstrained' (estimation occurs over all land grid squares globally) and 'constrained' (estimation occurs only within areas mapped as containing built settlements) versions of the datasets are available. Population count datasets are structured by male/female and 5-year age classes (plus a <1 year class).	Global	Mostly 100m, global mosaics and women of childbearing age have a 1km resolution	Estimate population count by grid cell and by age-sex. Several datasets are available: - Constrained individual countries 2020 (UN/non-UN adjusted) - Unconstrained global mosaics 2000-2020 - Unconstrained individual countries 2000-2020 - Women of childbearing age (15-49) in 2015	2000-2020 (unconstrained) 2020 only (constrained)
Population	Estimated population density per grid-cell.	WorldPop. https://www.worldpop.org/	Two population density datasets are available to download: (1) Unconstrained individual countries 2000-2020. Derived from the corresponding Unconstrained individual countries 2000-2020 population count datasets by dividing the number of people in each pixel by the pixel surface area. These are produce using an unconstrained top-down modelling method, which takes a global database of administrative unit-based census and projection counts and disaggregates them to grid cell-based counts. Estimation occurs over all land grid squares globally (unconstrained). (2) Unconstrained individual countries 2000-2020 UN adjusted. As above but using UN adjusted count datasets.	Global	1km	Estimated population density per grid-cell.	2000-2020
Population	Population count (GHS-POP)	European Commission Global Human Settlement Layer (GHSL). https://ghsl.jrc.ec.europa.eu/	Residential population estimates for target years provided by CIESIN GPWv4.10 were disaggregated from census or administrative units to grid cells, informed by the distribution and density of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding target year.	Global	Data for each available year can be downloaded at the 250m, 1km, 9 arcsec and 30 arcsec resolution.	Depicts the distribution of population, expressed as the number of people per cell.	1975, 1990, 2000 and 2015

Critical national infrastructure	Waterways, roads, railways, airports, ports	Humanitarian Open Street Map (OSM) Team. https://www.hotosm.org/	OpenStreetMap is a free, editable map of the whole world that is being built by volunteers largely from scratch and released with an open-content license. The data is made of elements, including nodes (used to mark locations), ways (a connected line of nodes used to represent roads, paths, rivers etc.), closed ways (ways that form a closed loop), areas (filled closed ways), and relation (which can be used to represent more complex shapes). All elements carry tags which describe the element in detail. It is possible to create custom extracts of OSM data and view how data has changed over time.	Global	Point data	Primary features relating to critical national infrastructure include aerial ways, aero ways, barriers, boundaries, buildings, highways, land uses, public transport, waterways.	N/A
Public services	Health facilities, education facilities	Humanitarian Open Street Map Team. https://www.hotosm.org/	As above.	Global	Point data	Primary features relating to public services include amenities (e.g., education, healthcare, public services), emergency sites (medical rescue, firefighters), healthcare sites, and others set our here: https://wiki.openstreetmap.org/wiki/Map_features#Properties.	N/A
Coral reef coverage	Satellite-based coral reef coverage dataset	UN Environment Programme, World Conservation Monitoring Centre. https://data.unep-wcmc.org/datasets/1	Approximately 85% of this dataset originates from the Millennium Coral Reef Mapping Project, of which 35% was validated (by IMaRS-USF and IRD-Noumea) and 50% remains unvalidated. Where no Millennium Coral Reef Mapping Project products existed, data were compiled from other sources, including the World Atlas of Coral Reefs (Spalding et al. 2001). The dataset is mostly fitted to ESRI's base layer.	Global	30m	Global distribution of coral reefs in tropical and subtropical regions	1954-2009
Mangrove forest coverage	Satellite-based mangrove coverage dataset	UN Environment Programme, World Conservation Monitoring Centre. https://data.unep-wcmc.org/datasets/5	The dataset was created mostly from satellite imagery processed at UNEP-WCMC or FAO. For a number of countries, existing (WCMC-012 (1997)) or newly available (vector) data were incorporated. The methodology is detailed in chapter 3 of Spalding et al. (2010).	Global		Global distribution of mangroves.	Mainly 1999-2003 (some earlier data for some countries)

Table 20 Summary of high-resolution exposure datasets available across the Caribbean.

6.3 Review of vulnerability indicators

Table 21 and Table 22 provide further details on two of the vulnerability indices that were reviewed as part of this study. This analysis assessed 18 conceptual frameworks, guidance documents, and indices relating to the conduct of vulnerability assessments; this included literature published by a variety of international development agencies and development financing organizations such as the United Nations Office for Disaster Risk Reduction (UNDRR), the United Nations Development Programme (UNDP), and the IDB, as well as non-governmental organizations (NGOs) and academic literature. The most appropriate indicators from this preliminary list were selected and data gathered.

	Indicators
Personal Wealth	Per capita income
	Percentage of households earning >USD75,000
	Median dollar value of owner-occupied housing
	Median rent (in dollars) for renter-occupied housing units
	Percent living in poverty
	Earnings (in $1 ,000) in all industries per square mile
Age	Median age
	Percent of population over 65 years
	Percent of population under five years old
	Birth rate (number of births per 1 ,000 population)
	Per capita Social Security recipients
Density of the built environment	Number of housing units per square mile
	Number of housing permits per new residential construction per square mile
	Number of manufacturing establishments per square mile
	Earnings (in $1 ,000) in all industries per square mile
	Number of commercial establishments per square mile
	Percent population change
	Average number of people per household

	Indicators
	Net international migration
Single-Sector Economic Dependence	Percent rural farm population
	Percent employed in primary extractive industries (farming, fishing, mining, and forestry)
	Land in farms as a percent of total land
	Value of all property and farm products sold per square mile
Housing Stock and Tenancy	Percent of housing units that are mobile homes
	Percent urban population
	Percent renter-occupied housing units
Race	Percent African American
	Percent Asian
Ethnicity	Percent Hispanic
	Percent Native American
Occupation	Percent employed in service occupations
	Percent of the population participating in the labor force
	Percent of civilian labor force unemployed
	Percent of population 25 years or older with no high school diploma
Infrastructure Dependence	General local government debt to revenue ratio
	Percent employed in transportation, communications, and other public utilities
	Per capita residents in nursing homes
	Per capita number of community hospitals
Gender	Percent females
	Percent female-headed households, no spouse present
	Percent females participating in civilian labor force

Table 21 The 42 socio-economic indicators across 11 themes which made up the original Social Vulnerability Index (SoVI). Adapted from Cutter et al. (2003).[93]

[93] Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. Social science quarterly, 84(2), 242-261. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/1540-6237.8402002

Composite Indicator	#	Indicator description
Exposure and susceptibility (PVI_{ES})	ES1	Population growth, average annual rate
	ES2	Urban growth, avg. annual rate (%)
	ES3	Population density (people/5 Km^2)
	ES4	Poverty, population living on less than US$1 per day PPP
	ES5	Capital stock in millions US dollar per thousand square kilometers
	ES6	Imports and exports of goods and services as a percent of GDP
	ES7	Gross domestic fixed investment as a percent of GDP
	ES8	Arable land and permanent crops as a percent of land area
Indicators of socioeconomic fragility (PVI_{SF})	SF1	Human Poverty Index, HPI-1.
	SF2	Dependents as a proportion of the working age population.
	SF3	Inequality as measured by the Gini coefficient.
	SF4	Unemployment as percent of the total labor force.
	SF5	Annual increase in food prices (%).
	SF6	Share of agriculture in total GDP growth (annual %).
	SF7	Debt service burden as a percent of GDP.
	SF8	Soil degradation resulting from human activities (GLASOD).
Indicators of (lack of) resilience (PVI_{LR})	LR1	Human Development Index, HDI [Inv][94]
	LR2	Gender-related Development Index, GDI [Inv]
	LR3	Social expenditures on pensions, health, and education as a percent of GDP [Inv]
	LR4	Governance Index (Kaufmann) [Inv]

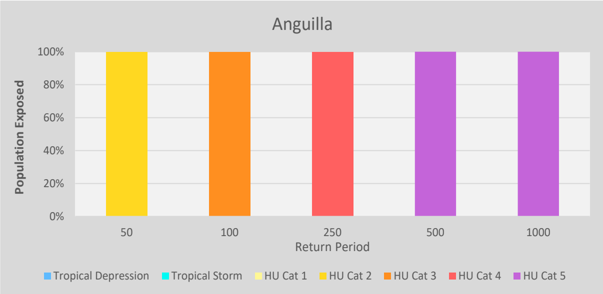
[94] [Inv] refers to the inverse

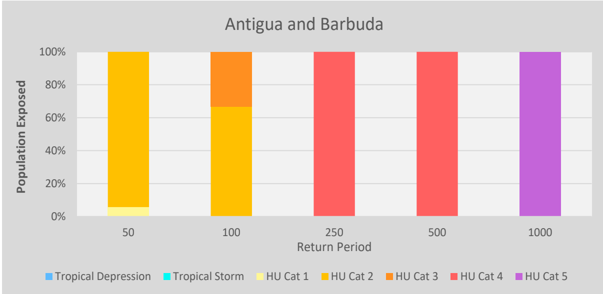
Composite Indicator	#	Indicator description
	LR5	Infrastructure and housing insurance as a percent of GDP [Inv]
	LR6	Television sets per 1000 people [Inv]
	LR7	Hospital beds per 1000 people [Inv]
	LR8	Environmental Sustainability Index, ESI [Inv]

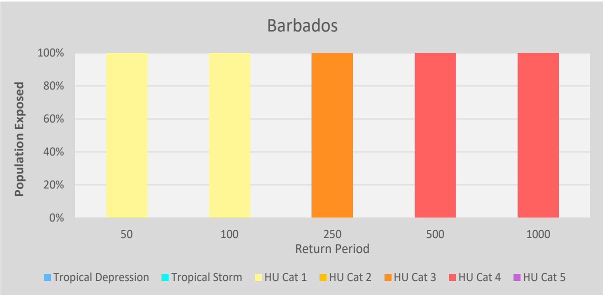
Table 22 Indicators of exposure and susceptibility (ES), socio-economic fragility (SF) and lack of social resilience (SR) used to estimate the total Prevalent Vulnerability Index (PVI). Adapted from Cardona, 2007.

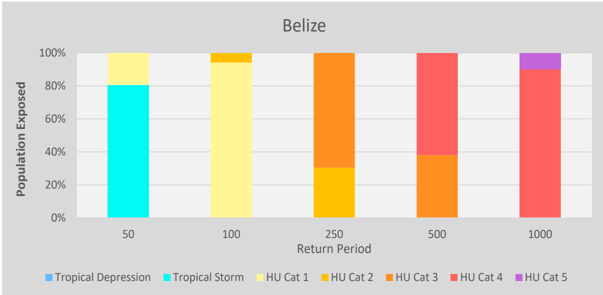
6.4 Country hazard modelling results

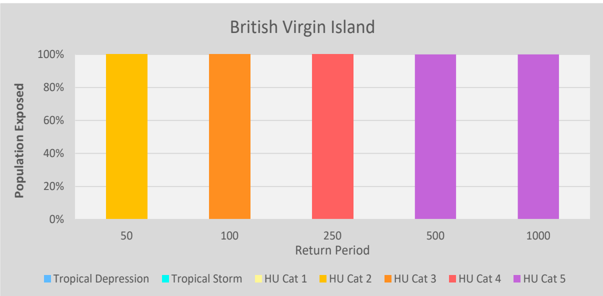
6.4.1 Tropical Cyclone Wind

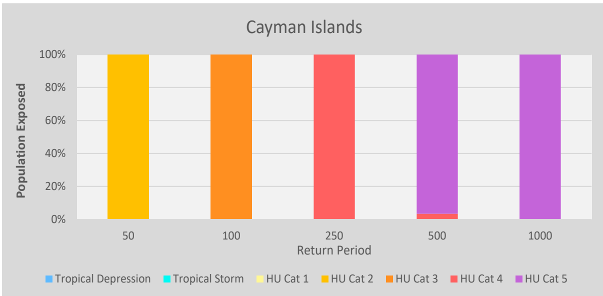


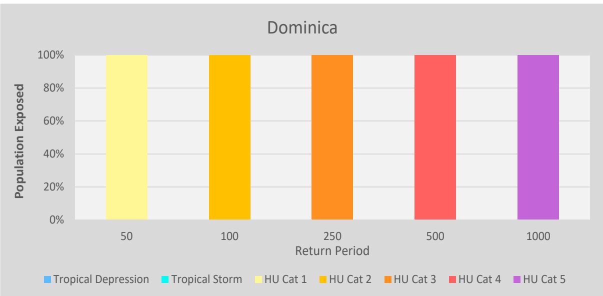


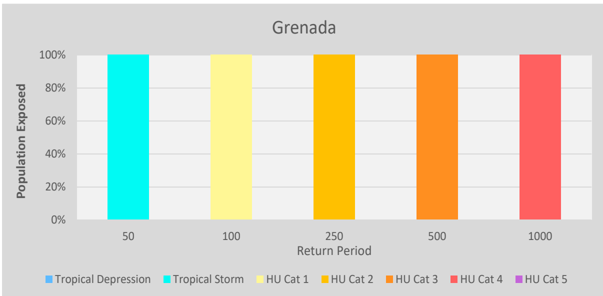


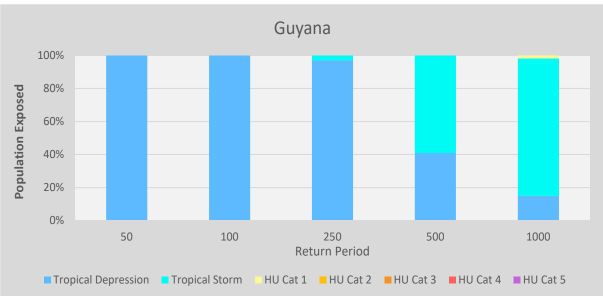


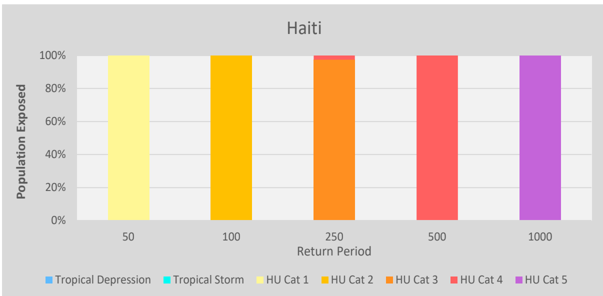


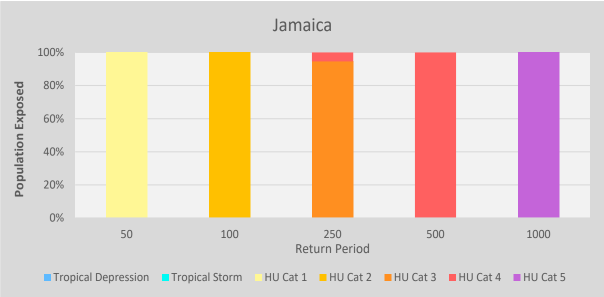


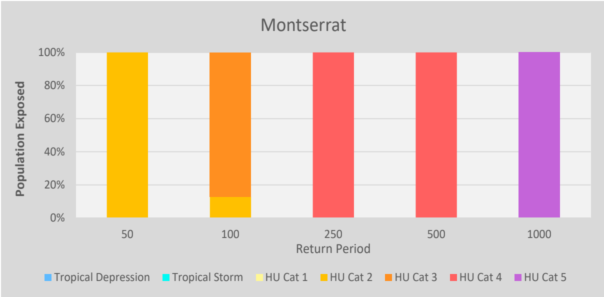


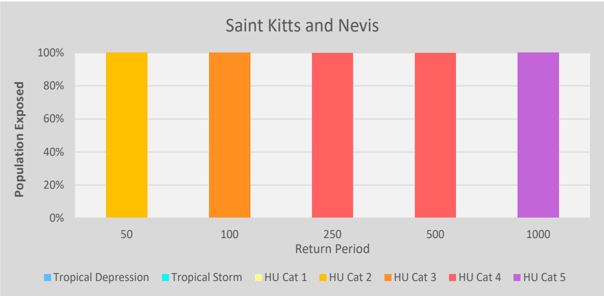


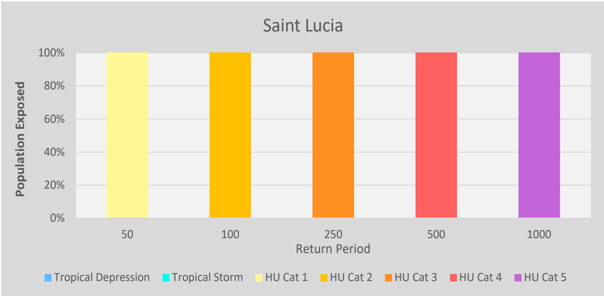


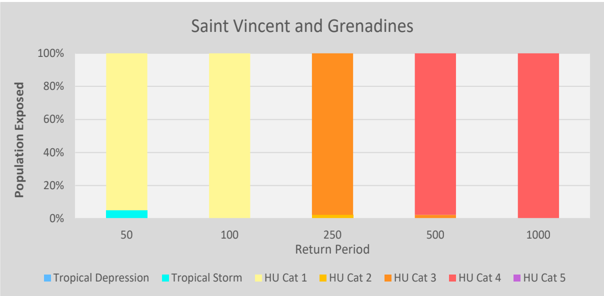


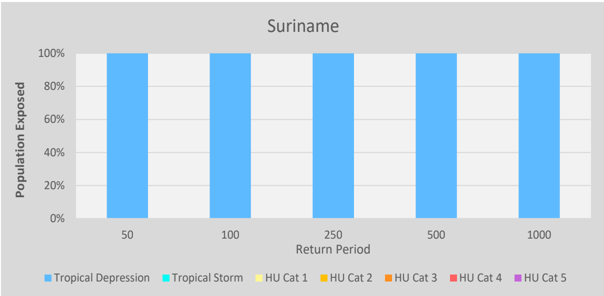

Jamaica
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

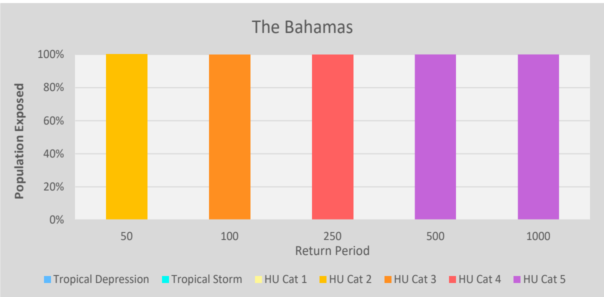

Montserrat
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

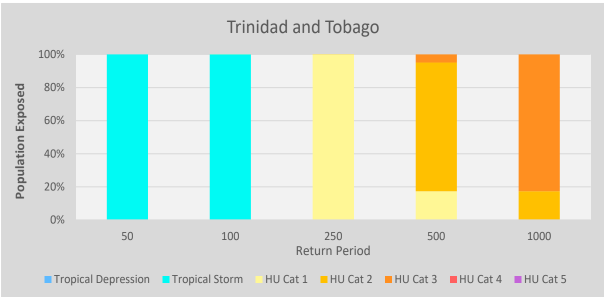

Saint Kitts and Nevis
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

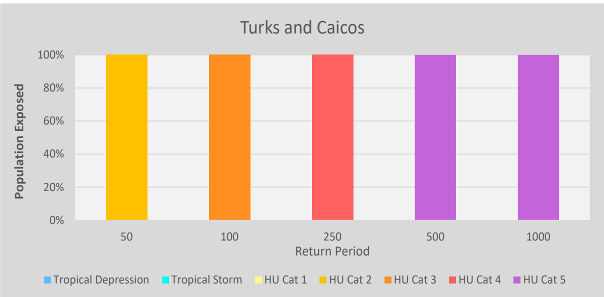

Saint Lucia
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5


Saint Vincent and Grenadines
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

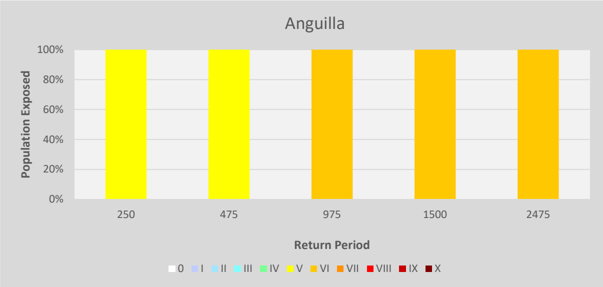

Suriname
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

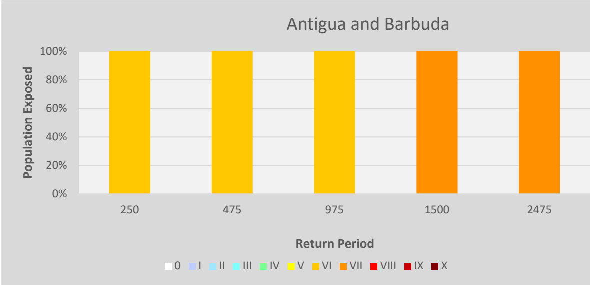

The Bahamas
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

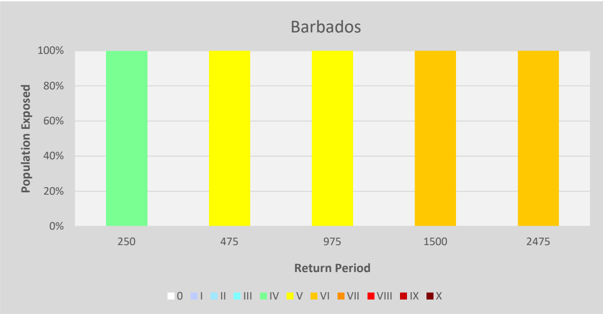

Trinidad and Tobago
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

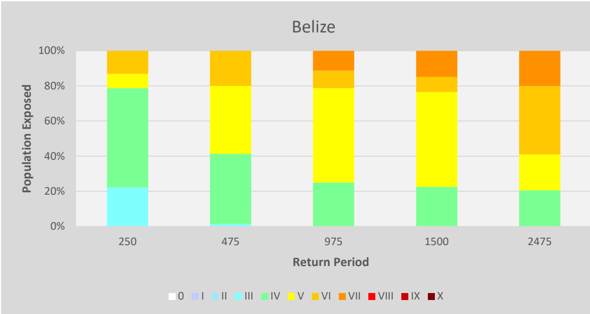

Turks and Caicos
Population Exposed
100%
80%
60%
40%
20%
0%
50
100
250
500
1000
Return Period
Tropical Depression
Tropical Storm
HU Cat 1
HU Cat 2
HU Cat 3
HU Cat 4
HU Cat 5

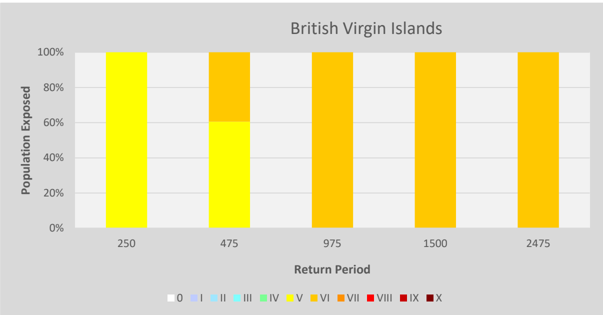
6.4.2 Earthquake shaking

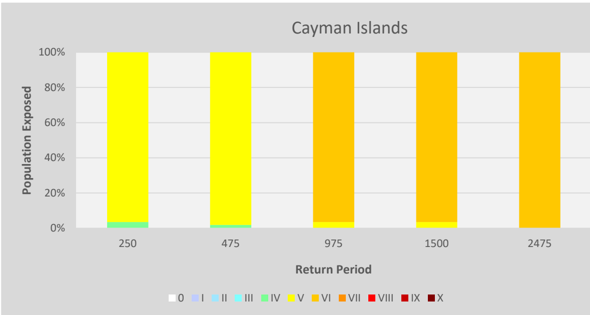


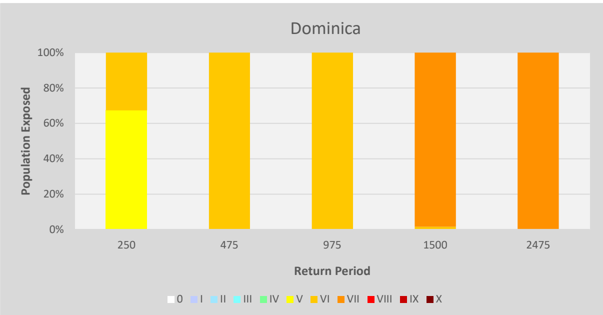


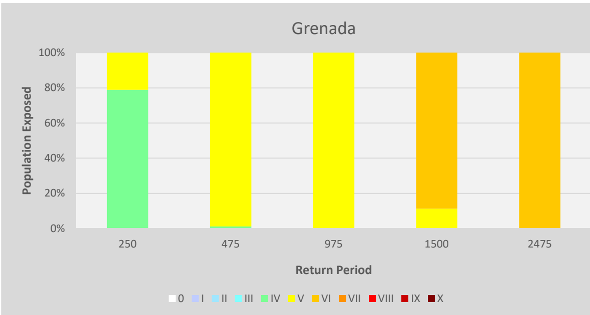


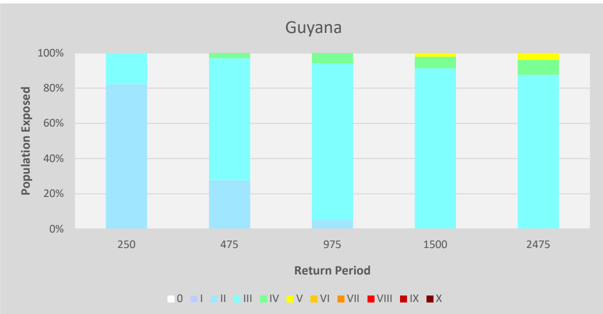


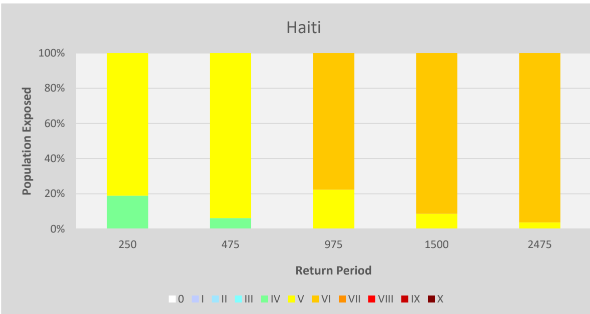


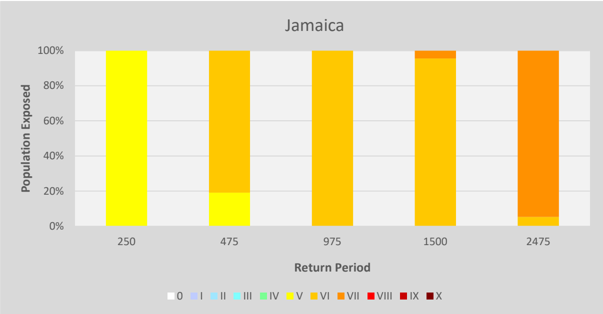


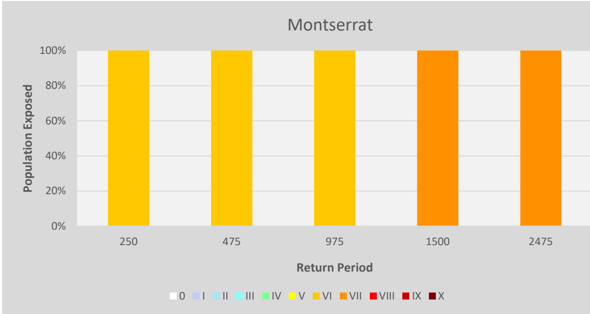


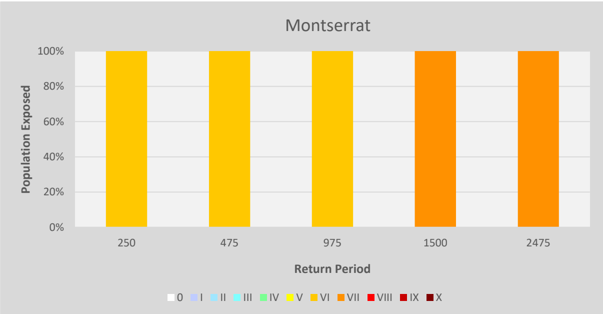


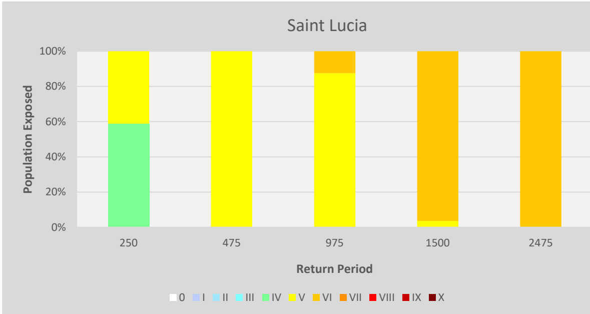


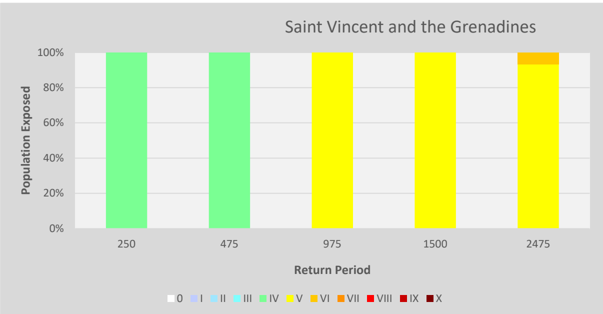


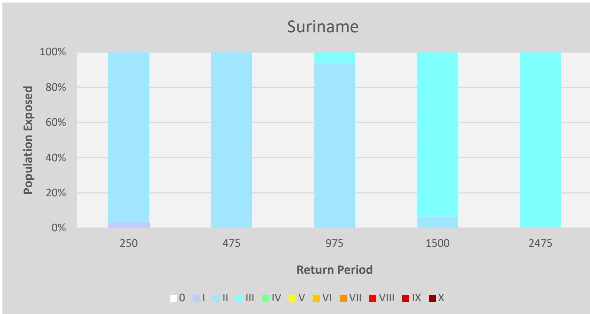

Jamaica
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X

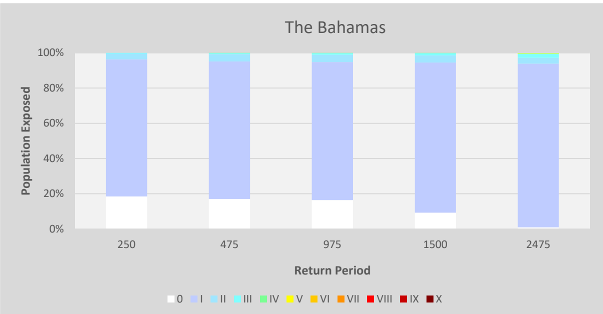

Montserrat
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X


Montserrat
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X


Saint Lucia
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X


Saint Vincent and the Grenadines
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X


Suriname
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X


The Bahamas
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
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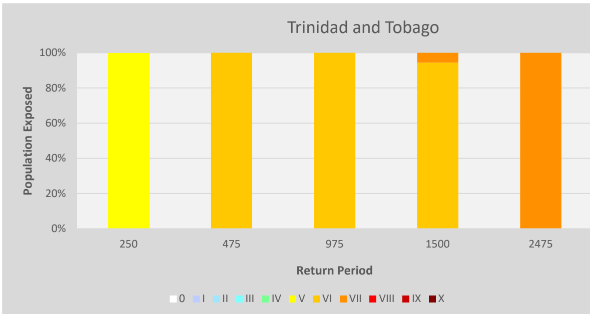
Trinidad and Tobago
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
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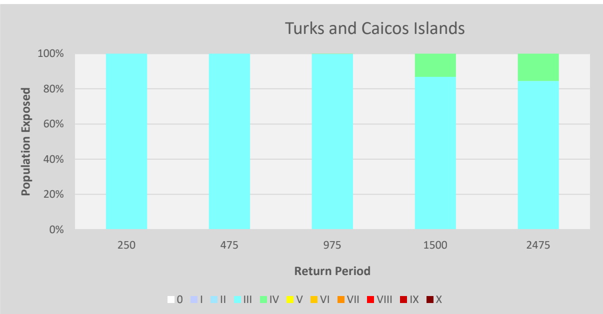
Turks and Caicos Islands
Population Exposed
100%
80%
60%
40%
20%
0%
250
475
975
1500
2475
Return Period
0 I II III IV V VI VII VIII IX X