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The use of technology and innovative approaches in disaster and risk management

A characterization of Caribbean countries' experiences

Luciana Fontes de Meira
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This document has been prepared by Luciana Fontes de Meira, Associate Environmental Affairs Officer in the Sustainable Development and Disaster Unit of the Economic Commission for Latin America and the Caribbean (ECLAC) subregional headquarters for the Caribbean, and Omar Bello, Economic Affairs Officer of ECLAC. Valuable data, technical inputs and reviews were provided by Colleen Weekes, an external consultant, and Artie Dubrie, Coordinator of the Sustainable Development and Disaster Unit, of the ECLAC subregional headquarters for the Caribbean.

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Acronyms

ACS	Association of Caribbean States
CANARI	Caribbean Natural Resources Institute
CARICOM	Caribbean Community
CBDRR	Community-Based Disaster Risk Reduction
CCCCC	Caribbean Community Climate Change Centre
CCORAL	Caribbean Climate Online Risk and Adaptation Tool
CCRIF-SPC	Caribbean Catastrophe Risk Insurance Facility Segregated Portfolio Company
CDB	Caribbean Development Bank
CDCC	Caribbean Development Cooperation Committee
CDEMA	Caribbean Disaster Emergency Management Agency
CReW	Caribbean Regional Fund for Wastewater Management
CREWS	Coral Reef Early Warning System
CWWA	Caribbean Water and Wastewater Association
DALA	Damage and Loss Assessment
DFID	Department for International Development (United Kingdom)
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
ECCB	Eastern Caribbean Central Bank
EU	European Union

FAO	Food and Agriculture Organisation of the United Nations
GCCA	Global Climate Change Alliance
GCF	Green Climate Fund
GEF	Global Environmental Facility
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HFA	Hyogo Framework for Action
IAEA	International Atomic Energy Agency
ICT	Information and Communications Technology
IDB	Inter-American Development Bank
IoT	Internet of Things
ITU	International Telecommunications Union
LAC	Latin America and the Caribbean
LiDAR	Light Detection and Ranging Technology
MPA	Marine Protected Area
OAS	Organisation of American States
OECS	Organization of Eastern Caribbean States
PAHO	Pan American Health Organisation
PDNA	Post-Disaster Needs Assessment
SAMOA	Small Island Developing States Accelerated Modalities of Action
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United National Environmental Programme
UN-ECLAC	United Nations Economic Commission for Latin America and the Caribbean
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNIDRR	United Nations Office for Disaster Risk Reduction
UNOOSA	United Nations Office for Outer Space Affairs
USAID	United States Agency for International Development
WASH	Water, Sanitation and Hygiene

Abstract

The application of technologies, research, development, promotion of innovative approaches and local knowledge to confront complex issues posed by hazards are important components of managing disaster risks and guiding informed decision-making. Hence commitments to support and enhance access to technologies and to foster innovative approaches to risk reduction, preparedness and resilient recovery are essential requirements for the management of current and future disasters in the Caribbean subregion. Considering the importance of Disaster and Risk Management (DRM), the aim of this study is to assess and discuss the application of technologies and innovative approaches related to DRM in the subregion. The study will consider the five pillars of DRM: risk identification, risk reduction, preparedness, financial protection and resilient recovery. It will examine the types of available and applied technologies, discuss selected innovative approaches, evaluate and recommend strategies to advance the use, accessibility and uptake of these in all five pillars of DRM in the Caribbean subregion. The research is expected to contribute to the ongoing global discussion on the use of technology and innovation for DRM, with special attention to the sustainable development challenges of the Caribbean Small Islands Developing States (SIDS).

Introduction

Structural constraints combined with physical exposure create conditions under which environmentally vulnerable developing countries cannot effectively invest disaster risk mitigation strategies (ECLAC, 2019b). Consequentially, these countries are more vulnerable to the effects of large-scale disasters[1] or recurrent small-scale events and with the potential to undermine their long-term economic, social and environmental viability. Caribbean countries specifically, face a combination of physical and structural vulnerabilities, such as the proximity of population and essential infrastructure to the coastline, dependence on external financing, limited capacity to mobilize domestic resources and high levels of external public debt that pose barriers to the achievement of their domestic and international development targets such as the Sustainable Development Goals (SDGs) of Agenda 2030 (ECLAC, 2018a). Therefore, the vulnerability of the Caribbean subregion to disasters' impacts has to be considered in any discussion on the economic performance and other sustainable development prospects of the subregion.

Caribbean SIDS[2] must consider these factors in the elaboration of national and local development plans and include DRM as an important part of this process. One of the central objectives of these development plans should be to manage the risk of disasters and to integrate resilience[3] into planning

[1] Disasters result from a combination of two factors: (i) natural phenomena capable of triggering processes that lead to physical damage and loss of human lives and capital; and (ii) vulnerability of individuals and human settlements to such events. There are three relevant kinds of vulnerability: (i) infrastructural, which includes inadequacies in enforcement of building codes and spatial planning, for example; (ii) social, including, for example, poverty and income inequality, preconditions that can amplified the effects of a disaster; (iii) and disaster response, with failures related to the implementation of a national disaster plan. Vulnerability is a prerequisite (manifested during the disaster), as well as an indicator of the exposure of the physical and human capital and of the capacity of individuals, households, communities and countries to endure and recover from disasters (ECLAC, 2014).

[2] The original definition of the SIDS described them as "low-lying coastal countries that tend to share similar sustainable development challenges, including small but growing populations, limited resources, remoteness, susceptibility to natural disasters, vulnerability to external shocks, excessive dependence on international trade and fragile environments". In order for a country to be considered a SIDS, four conditions must be fulfilled: 1) small in size; 2) independent; 3) developing; 4) low coastal line.

[3] Resilience is defined as "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure " (UNDRR, 2005).

strategies. The planning stages should therefore include identifying the risk of disasters and having measures that reduce this risk, such as strengthening infrastructure and territorial planning, preparation and financial protection.

The current institutional landscape that shapes the conditions under which DRM is to be successfully accomplished is further guided by the Sendai Framework for Disaster Risk Reduction 2015-2030[4] (SFDRR). This framework builds on the Millennium Development Goals, the 2030 Agendas and its Sustainable Development Goals (SDGs), the Hyogo Framework for Action,[5] and the Small Island Developing States (SIDS) Accelerated Modalities of Action or SAMOA Pathway. Both the Hyogo Framework for Action (HFA) for Disaster Risk Reduction (DRR) 2005-2015 and its successor, the SFDRR, include guidelines to facilitate the integration of the DRM agenda into regional and national disaster management frameworks. Aligned with this overall strategy, the implementation of the Sendai Framework in the Americas and the Caribbean was discussed during the Sixth Regional Platform for DRR in June 2018. The outcomes of the discussion were included in the Third High-level Meeting of Ministers and Authorities on the Implementation of the Sendai Framework for Disaster Risk Reduction 2015 – 2030 in the Americas and the Caribbean (Cartagena Declaration) [6]. The Cartagena Declaration urges countries to develop and strengthen DRM plans and strategies at the national and local levels in line with the existing Regional Action Plan[7] for implementation of the framework in the Americas.

In addition to promoting national instruments for DRM, the SFDRR calls for the "use and expansion of thematic platforms of cooperation, such as global technology pools and global systems to share know-how, innovation and research and ensure access to technology and information on DRR". The SFDRR also highlights the enhanced role for science, technology and innovation in modelling, early warning systems solutions, building resilient communities and the importance of increasing education and technical capacities in securing successful disaster resilience. This message is also emphasized in the Cartagena Declaration that aims to strengthen the development and usage of methodologies and science-based tools to implement disaster prevention and preparation measures in the region. Each of these inter-governmental outcome documents consider technology and innovation as required enablers for sustaining informed decision-making for managing disaster risks and for the implementation and monitoring of targets and goals.

Global, regional and national commitments to enhancing access to technology[8] and promoting innovative approaches to DRR[9] , as well as those to exchanging information and integrating local knowledge into DRR decision-making have been deemed essential for addressing the current and future challenges to building resilience. Applying technology and innovative approaches to DRM can help countries in several ways including: monitoring and managing ecosystems, preventing biodiversity loss and damage to natural barriers that protect against disaster impacts; averting food crisis with improved drought resistant crops and better land management strategies; improving water supply and treatment,

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4 Agreement available at: https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

5 Agreement available at: https://www.undrr.org/publication/hyogo-framework-action-2005-2015-building-resilience-nations-and-communities-disasters.

Cartagena Declaratio - Third High-level Meeting of Ministers and Authorities on the Implementation of the Sendai Framework for Disaster Risk Reduction 2015 – 2030 in the Americas and the Caribbean. Declaration available at: https://eird.org/pr18/docs/declaracion-de-cartagena.pdf.

7 Document available at: https://www.preventionweb.net/english/professional/policies/v.php?id=52286&pid:184.

8 The term innovation has many definitions, in this study, innovation will be considered is its broader and simple meaning of "the act or process of introducing new ideas, devices, or methods" (Merriam-Webster). Technological capabilities involve the ability to learn, understand and apply scientific knowledge and skills to solve problems, the ability to learn, understand and master the use of existing technologies and produce new technologies and, finally, the ability to innovate. Technology is hereby defined as application of scientific knowledge to practical purposes.

9 Although often used interchangeably, disaster risk management and disaster risk reduction have different meanings. Whereas disaster risk reduction measures are aimed at identifying and decreasing underlying drivers of risk, disaster risk management can be seen as the application of disaster risk reduction policies and strategies to prevent new disaster risks, reduce existing disaster risks, and manage residual risks, contributing to the strengthening of resilience and reduction of losses.

irrigation and sanitation with low cost solutions; addressing disease epidemics in a timely and effective way and improving early warning systems with the usage of observation tools, geographical information systems (GIS) and global positioning systems (GPS). It can be an instrument of inclusion, allowing a more consistent and adequate collection of disaggregated data and the involvement of indigenous communities and marginalized groups in the development and implementations of local plans and strategies.

Many lessons on the ways in which technology and disaster risk management strategies interact can be drawn from current experience with the COVID-19 pandemic. This highly contagious virus that spread globally has disrupted economies, livelihoods and halted the normal pace of life across the globe. The severity of the situation and the urgent responses it required brought practical and ethical questions on the use of technologies and innovative approaches for such emergencies, especially when related to social control. On one hand, transferring activities to the digital world could have positive outcomes by changing the way we develop and maintain social ties and connections and go about our daily activities. For example, decreasing traffic congestion and air pollution by lowering unnecessary commuting, changing the necessity of company location in high-cost urban areas, reducing land and energy consumption as telework becomes more acceptable, and inspiring teachers and educational institutions to create and introduce new pedagogical tools more engaging and aligned with the current times. On the other hand, however, the application of digital technologies raises ethical questions in terms of privacy and government interference in private life, especially when it comes to personal data being used for surveillance.

Box 1
COVID-19 pandemic and innovative approaches to disaster and risk management

(i) Testing and response capacity: For a highly contagious virus that can be spread by asymptomatic patients, quick and broad testing of potentially affected people has been deemed essential to contain the pandemic. Governments have adopted different approaches in this regard, from mass testing to exclusively testing symptomatic people. Drive-through testing, initially implemented by South Korea, has been developed to fast track procedures and limit transmission in health facilities. Moreover, private companies have attempted to create and commercialize rapid testing kits, aiming to increase testing capacity in worst affected locations. Another approach broadly utilized is the use of telemedicine for diagnosis, care and to prevent people from going to health facilities. Finally, the usage of 3D printers to produce large quantities of protective gear is another example of how technology can be applied in disaster response to quickly improve and adapt medical devices, testing and protective gear.

(ii) Early warning and surveillance: Although contact tracing is a traditional approach when it comes to pandemics, technology usage in this process has improved the speed and accuracy of the data collected. For example, the usage of phone call detail information to trace movement and contact to enforce quarantine measures. Surveillance mechanisms that already existed, such as cameras and sensors, also started being used to enforce such measures. Many private sector companies also started offering app solutions for self-tracking, symptom checks and community notifications. Innovations in the management of information have also been observed with the surge of global and national platforms to openly report caseload and health system capacities. Academic and news outlets have also developed open data platforms and opened their resources to the public for information/knowledge sharing.

(iv) Research and cure: In the rush to develop a vaccine and effective treatment protocols, the medical sciences field has been reshaped. Several private companies have engaged in research, processing or other actions to support medium- and long-term response efforts. IBM, for example, contributed the world’s largest supercomputer toward identifying chemicals that limit COVID-19 transmission. Moreover, a number of public and public-private initiatives have shared their data, research and computation power to develop genomic maps, treatment and vaccines. Collaboration spaces for data scientists have also been restored. These include, for example, Data Against COVID, a channel for data scientists looking to collaborate on COVID-19 -related data science projects; and Help With COVID, a Y Combinator (which provides funding for start-ups) created volunteer-to-project matching website for COVID-19 -related software projects.

(v) Online education and telework: With "social distancing" becoming an imperative new guidance, ways of conducting meetings, learning, interacting with colleagues and even balancing personal life and work-related tasks have been tested. By the end of this "forced experiment", the coronavirus disruption might create a new reality in which digital connectivity to perform everyday tasks, including telework, is seen as the new normal.

Source: Based on MacDonald, Sean (2020). The Digital Response to the Outbreak of COVID-19. Available at: https://www.cigionline.org/articles/digital-response-outbreak-covid-19.

Despite identified need and benefits of nurturing the science-DRM interface, the 2011 Mid-Term Review of HFA[10] identified that little improvement had been achieved globally in coordination of scientific entities and meeting the demand for greater knowledge and building of technical capacities for DRM. Weichselgartner and Kasperson (2010) have identified a series of barriers in translating scientific knowledge into action for DRM. Many of the gaps and difficulties identified are functional, social and structural factors in the science and policy interface including differing objectives, needs, and priorities among stakeholders dealing with disaster and scientific organizations, different institutional settings, as well as differing cultural values and understanding between knowledge generators and knowledge users.

Considering the importance assigned to the role of technology and innovation in the field of DRM, the aim of this study is to assess and discuss the application of technologies and innovative approaches related to DRM in the Caribbean subregion. The analysis will be based on the five pillars of DRM: risk identification, risk reduction, preparedness, financial protection and resilient recovery. The paper will examine and discuss three key questions:

(i) What are the most common technologies and innovative approaches used globally to support DRM?

(ii) What kinds of technologies or innovative approaches to DRM currently available are being used or could potentially be used by Caribbean SIDS?

(iii) What type of architecture and resources (financial, institutional and specialized skills) would governments need in order to apply and foster technology usage and innovative approaches to DRM in the Caribbean subregion?

The first part of the study will focus on a description of the major global trends in technological applications and innovative approaches for DRM. The second part will focus on disaster trends in the Caribbean subregion and identify progress, key stakeholders and priority areas in the usage of technology and innovative approaches for DRM. Based on the results, the study will recommend strategies to advance the use, accessibility and uptake of technologies and innovative approaches in all five pillars of DRM in the Caribbean subregion. The research is expected to contribute to the ongoing global discussions on the use of technology and innovation for DRM.

[10] Document available at: https://www.preventionweb.net/publications/view/18197.

I. Technology and innovation in disaster and risk management

Population growth, urbanization and growing environmental challenges add complexity to the decision-making process related to disasters. These challenges are further accentuated in SIDS that already face territorial exposure and limited fiscal space. In addressing this complexity, governments in the Caribbean and globally have been adopting a broader view of risk in order to manage multiple hazards and vulnerabilities[11] in an interconnected way to better utilize scarce resources. In this regard, technology and Innovation (TI) can be used to support the practice of DRM in times of crisis, as well as in planning and reconstruction. On one hand, utilizing the best available technology may enable more focused disaster risk assessment, improve forecasting, prevent human losses with efficient early warning systems, and contribute to strengthening resilience building/reconstruction strategies. On the other hand, fostering innovative approaches may uncover different ways of working collaboratively, and may also identify tools, data collection and management methods, risk communication and knowledge sharing approaches. Appropriate technologies and innovative approaches can be used to support all five phases of DRM, as illustrated in Table 1.

Table 1
Five Pillars of Action for DRM

	Pillars of action	Description	Examples of technology usage and innovative approaches
Pillar 1	Risk identification	Better identification and understanding of disaster risk through capacity building for assessments and analysis.	Exposure identification and mapping; Models; Databases: Participatory Risk Mapping (crowdsourcing), Big data.
Pillar 2	Risk Reduction	Avoiding the creation of new risks and seeking the reduction of existing risks by considering and accounting for disasters risk in the public policies and investments	Ecosystem based management and adaptation; Community based ecosystem and DRM; Hybrid solutions; Integrated water resources and coastal zone management; Earthquake-resistant constructions; Communication-network; Network analysis applications and software and system;

11 Vulnerability is the inability to resist a hazard or to respond when a disaster has occurred. Vulneraiblities can be assessed through models and indexes utilizing pre-established parameters used to evaluate a combination of different factors.

	Pillars of action	Description	Examples of technology usage and innovative approaches
			Knowledge, communication, information, and education technologies.
Pillar 3	Preparation	Improved capacity to manage crises by developing disaster management and forecasting capabilities	Resource databases; coordination and resource allocation tools; Knowledge networks; Weather forecast: real-time tracking of storms; Home sensors (fire, and other emerging); Cluster approach and tools Mobile Response; Awareness raising technologies and tools; Social Media Technologies: UAVs and other search and rescue robotics tools; Sensors.
Pillar 4	Financial Protection	Increased financial resilience of governments, the private sector and households through financial protection strategies	Blockchain, Crowdfunding New insurance models Microinsurance schemes.
Pillar 5	Resilient Recovery	Faster and more resilient recovery through support for planning reconstruction processes	Unmanned aerial vehicle (UAVs); Coordination and resource allocation tools and technologies; "Build back better" technologies; Livelihood and disaster assessments; Improved sanitation technologies; Water access and purification technologies; Medical technologies.

Source: Authors based on Global Facility for Disaster Risk Reduction (GFDRR), "Managing Disaster Risks for a Resilient Future -A Work Plan for the Global Facility for Disaster Reduction and Recovery 2016 – 2018" and Cracco, M. & Charrière, M. (2016) and Non-Exhaustive List of Technologies and Tools for Disaster Risk Reduction. EPFL-CODEV MOOC "*A Resilient Future: Science and Technology for Disaster Risk Reduction"* additional material.

In terms of governance in the Caribbean subregion, mobilization and coordination of expertise among different government agencies and amongst countries, including the support of the private sector and civil society, is essential for long-term DRM and for guaranteeing that countries are able to access and make use of the best and most recent resources available. In the Caribbean SIDS, international frameworks have facilitated the integration of the international DRM agenda into regional DRM strategies. One key example is the Regional Comprehensive Disaster Management (CDM) Strategy 2014-2024 set forth the Caribbean Disaster Emergency Management Agency (CDEMA) and endorsed by the respective governments of the Caribbean Community (CARICOM) after a series of stakeholders' consultations in 2013. The Caribbean CDM Strategy draws from key sub-regional development agendas and harmonises the priority thematic areas advocated in CARICOM's Strategic Framework 2015-2019, in the Organisation of Eastern Caribbean States' (OECS) Saint George's Declaration of Principles for Environmental Sustainability, and the Caribbean Community Climate Change Centre's (CCCCC) Regional Framework for Achieving Development Resilient to Climate Change 2009 – 2015 (CDEMA, 2014, p. 31-33). The strategy puts forward four priority areas for safer, more resilient and sustainable countries: strengthened institutional arrangements for CDM; increased and sustained knowledge management and learning for CDM; improved integration of CDM at sectoral levels; and strengthened and sustained community resilience (CDEMA, 2014).

The CDM Strategy provides a critical policy framework that supports the advancement of the Caribbean's developmental priorities as well as the integration of best practices into national DRM policies, strategies and legislation. This Strategy references technology transfer as a priority area, highlighting Information and Communications Technologies (ICTs) as a cross-cutting theme to be considered across all planned actions to facilitate greater collaboration and learning. CARICOM's strategic framework also emphasized requirements for a technology driven economy. Despite their reference to the theme, both documents have a narrow focus on possible technology uses for DRM. A more focussed approach is observed in the Regional Framework for Achieving Development Resilience to Climate Change, which explicitly lists as priorities innovation and technological investment in areas such as low–carbon technologies and resilient buildings. Since the goals and activities supporting climate change adaptation and DRM are complementary, particularly for the Caribbean SIDS, this document can contribute as a positive example of the synergies between the two issues. Moreover, both climate change as well as the risk of disasters not only call for strong collaboration between all government sectors and society, but also demands creative and innovative solutions that allow countries to build stronger communities and infrastructure able to withstand both threats, often with limited resources.

DRM pillars are fully interrelated and must be accompanied by an enabling institutional, political, regulatory and financial environment that allows for the allocation of resources, roles and responsibilities. While regionally most planning instruments have been developed in alignment with the SDGs and have incorporated the active principles of DRM, including the Five Pillars of Action (ECLAC, 2019b), they tend to have a more conservative approach when it comes to the application of technology and innovative approaches for DRM. The application DRM pillars as well as their interaction with broader development issues and examples of technologies and innovative approaches will be further elaborated in the following sections.

Pillar 1. Risk identification

The successful management of disaster risk necessitates a full understanding of the hazards, exposure and vulnerabilities that exist within a community. It requires the identification of vulnerable societal, economic and environmental elements and the interactions of these within the targeted areas. National management plans which govern DRM efforts must therefore be informed by supporting data such as detailed risk maps and profiles, updated economic statistics and national accounts[12], and ex-ante disaster assessments to ensure the development of appropriate preventative and corrective measures and support evidence-based decision-making. In addition to collecting data and information, it is important to ensure that the data is available, shareable and usable by all stakeholders. Geo-information including geo-spatial databases are fundamental for planning processes and decision making.

Having a robust baseline with accurate and updated data is a must. In this regard, geospatial tools can be particularly useful for risk identification. These types of applications give a broader view of terrestrial processes that give rise to disasters, which can be further enhanced when combined with statistical modeling for building exposure data. This type of remotely sensed data sourcing for exposure is particularly useful in countries having limited assess to data collection resources, frameworks and agencies (Poljanšek, K., et al (Eds.), 2017). Hazard maps, for example, combining different approaches and geospatial technologies such as drones, airplane sensors and satellites provide graphic information on disaster risk that can be used for assessments, preparedness and evacuation. They are also an essential component in land and urban planning and can be a key instrument in post-disaster assessments. Further, they assist in a more efficient collection of hydrological and topographical data, making it possible to create numerical models and detailed infrastructure maps that provide accurate graphic information on

[12] "Ecosystem service accounting", for example, is a structured way of measuring the economic significance of nature that is consistent with existing macro-economic accounts and provides a sustainable and reliable way of consistently collecting and analysing environmental data.

risk and vulnerability in certain areas. Remote sensing can also be applied when in-situ surveys are not available or unreliable.[13]

Unmanned aerial systems, commonly referred to as drones, for example, are cost-effective, easy to deploy, and give disaster response teams the ability to survey large-scale or inaccessible disaster zones in a safe and efficient manner. Offering high resolution outputs, they can be used with satellite imagery and, in some instances, may be superior for spatial analysis during periods of heavy cloud cover, as is often the case after hurricanes. Advancements in drone technology also unlock new possibilities in the field of disaster relief such as logistical support and transportation of emergency medical supplies to isolated communities (Izumi et al., 2019).

Another approach to risk identification is the use of vulnerability indices, combining hazard, risk and vulnerability analysis as a type of assessment to be applied in a range of situations from global to community level analysis. These tools are useful in making comparisons between areas/countries/regions and for cross-learning between different stakeholders. At a global level, there are a number of composite indicators to assess disaster risk that include vulnerability as one of the risk's dimensions next to hazard and exposure such as, for example the WorldRiskIndex and the INFORM Index (Poljanšek, K., et all (Eds.), 2017).

Pillar 2. Risk reduction

In this second pillar, instruments such as legislation, institutions, policies and public-sector investment programmes are critical to reducing existing risks and preventing the development of new ones.

The promotion of updated spatial planning and zoning legislation is crucial for the sustainable development of living areas, as these instruments can reduce the proliferation of unplanned settlements and allow critical infrastructure (e.g. electrical and telecommunications networks, power generation facilities, ports, and waste and water management systems) to be properly designed and situated to withstand the most common threats. Seismic micro-zoning of urban areas, for example, considering soil conditions to design seismic coefficients for different types of structures, demonstrates a multidisciplinary approach to dealing with territorial planning that combines geology, seismology and structural engineering (Izumi et al., 2019a).

The modernization of building codes and related regulations is also key to ensuring the resilience of building stocks, although it can be often challenging to enforce and monitor the application of these codes. The use of concrete, masonry and steel reinforcements during reconstruction and any new developments has proven beneficial to mitigate disaster damage to essential infrastructure (ECLAC, IDB, PAHO, 2020).

Experiences and research around the world have also demonstrated the benefits of investing in ecosystems-based approach or a hybrid approach using hard infrastructure combined with natural solutions to reducing risk or reconstructing affected areas. Marine and terrestrial ecosystems function as natural protective barriers, mitigating hazard impacts and reducing socio-economic vulnerability as they sustain livelihoods and provide essential goods. Although the apparent higher costs and complexity of utilizing ecosystem-based solutions against disasters may limit its broader use, maintaining and restoring ecosystems as natural infrastructure may be more beneficial when compared to engineered structures, considering the full range of services provided (Cohen-Shacham, E., 2016).

Similarly , the active involvement of potentially affected communities in disaster risk identification, utilizing Community-Based Disaster Risk Reduction (CBDRR) or Community Based Disaster Risk

[13] Global population data, for example, are available from the LandScan Global Population Database which provides information on the average population over 24 hours and in a 1 km resolution grid or the open WorldPop database, which provides estimated population counts at a spatial resolution of 100 metres x 100 metres through the integration of census surveys, high- resolution maps and satellite data (Poljanšek, K., et al (Eds.), 2017).

Management (CBDRM) strategies in the planning process allows for the view of the communities and their risk perceptions to be included in evacuation and preparedness plans. This type of assessment allows for the participatory engagement of different stakeholders, decreasing the gap between communities, governments and researchers. These inclusive forums provide a space to discuss and review findings and ideas to include the consensual outcomes in the more formal process at the government planning level (Izumi et al., 2019a). In the case of small and medium-scale disaster events with frequent occurrence, this type of approach becomes particularly useful in helping planners to better understand vulnerability and hazard patterns.

Technology is an essential tool in broadening and democratizing decision-making processes when it comes to DRM. The broader usage of mobile and smartphone technologies, combined with improved knowledge management systems, has facilitated the participation and broadened role of community engagement in disaster and risk reduction (Poblet et al., 2014). Such engagement would have members of the community represent the following:

- People as sensors: Usage of data generated by internal sensors of mobile phones for DRM.
- People as social computers: Collection, analysis and usage of data generated by usage of apps and social media.
- People as reporters: Users offer their own information of events (e.g. taking a photo of damage, tweeting about weather conditions, etc.).
- People as microtaskers (crowdsourcing): Users create content such as adding roads or buildings to satellite images. For example, the Open Cities Mapping initiative.

Crowdsourcing[14] is gaining increased recognition within the disaster management community. For example, the 2019 Global Assessment Report on DRR emphasized its contribution to the furtherance of risk science when combined with open data and open-source software. Moreover, GFDRR launched an Open Data for Resilience Initiative in 2011 to: (i) increase public access to risk information and open data platforms; (ii) promote community mapping and crowdsourcing; and (iii) facilitate risk communication and analysis by decision-makers in planning, preparedness and response activities (GFDRR, 2019).

With ethical and regulatory implications still to be debated and fully understood, the use of crowdsourcing in local and real time information can be obtained and used for emergency or post-disaster matters to gain a better understanding of practices and processes that have worked and what can be improved in an emergency procedure (ITU, 2019). The collection of data on people's movements during an emergency utilizing mobile phone data, for example, can be useful in organizing emergency assistance planning, logistics and in the distribution of relief efforts.

Pillar 3. Preparedness

While risks can be identified and addressed, they cannot be completely eliminated, nor their impacts avoided. In this regard, this pillar contributes to an organized transition from response to recovery through improvements and capacity building in observation, forecasting, research, monitoring and early warning systems.

As mentioned in pillar 1, production, accessibility and application of reliable data are the basis for improving preparedness. However, public sector officials and other staff also need the necessary tools, knowledge and capacities to transform data into applicable policies and plans. Knowledge management

[14] Crowdsourcing is the practice of engaging a 'crowd' or group for a common goal, often innovation and/or problem solving, and it is powered by technologies such as internet and social media. It can involve paid and unpaid tasks and involve the collection of information, opinions, or work.

systems, for example, can be used to facilitate chains of communication between the scientists working at the forefront of hazard detection and the stakeholders responsible to responding to it (ECLAC, 2017). Data and information management technologies are also important for shelter management at times of emergencies, especially to record data on affected population and vulnerable people and to make it easily sharable and available to different government departments allowing for a better organization of resources and targeted aid.

Telemetry[15] systems help collect and disseminate real time data for use by disaster management agencies, allowing for an appropriate response to be initiated. These systems are essential for disaster preparedness as they collect data from real time sensors, process this data (e.g. through tools such as predictive simulation), and facilitate the issuance of early warning and evacuation orders or the creation of interactive information services for the public to access via the internet (Suciu et al., 2018, p. 1; Izumi et al., 2019). Accordingly, ICT platforms are indispensable for propagating these types of alerts through various output devices (including sirens, radio, email, short message service (SMS) and cellular broadcasting) by enabling the automated dissemination and receipt of hazard notifications via integrated Common Alerting Protocol systems. Additionally, disaster prevention radio systems can also assist in transmitting disaster information, warnings, and evacuation orders throughout urban areas or to individual receivers and households through loudspeakers (Izumi et al., 2019a).

Community-based approaches to preparedness fostering local ownership of risk reduction initiatives as well as continuous awareness campaigns are also important. ICTs, including social media networks, are essential tools for increasing the resilience of a population through awareness raising and sensitization. Social media has the potential to increase the knowledge of hazards, allow for data collection, give voice to people and provide information on logistic and humanitarian needs (ITU, 2019).[16]

Artificial intelligence (AI) may also significantly support disaster preparedness. AI has been used in image recognition of satellite photos post-disasters to identify damaged buildings, impassable roads and other type of damage. AI can also be used to analyse and validate data obtained from social media and make predictive analyses, given that it is able to process multiple data streams and eliminate unreliable data for more accurate responses. Artificial Intelligence for Disaster Response (AIDR), for example, was created to process the large number of tweets generated during a crisis using machine learning. The software, which is open source for those who work in crisis response, is able to collect tweets based on hashtags and keywords and classify them by topics using AI (ITU, 2019).

The internet of Things (IoT) is also a valuable tool for disaster management.[17] For example fire sensors can alert for hazards and potentially dangerous situations from inside a household. Other types of sensors can be used to detect earth movements that signal earthquakes or to monitor increases in

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15 Telemetry is the collection of measurements or other data at remote points and their automatic transmission to receiving equipment for monitoring.

16 Several social media platforms such as Facebook (http://www.facebook.com), Twitter (http://www.twitter.com) and the search engine Google (http://www.google.com) have implemented special features for emergencies. Twitter, for example, has implemented the Alerts feature, in which alerts are sent instantly to users as either tweets or converted to regular text messages. Facebook's Crisis Response app allows users to mark themselves as safe (Safety Check), provide or seek help, donate money, and receive information (ITU, 2019). Facebook has also a Disaster Maps tool showing where users are located, moving to and whether they are using the Safety Check feature. This tool has been used by relief organizations to identify, for example, where Internet connectivity required restoration in Puerto Rico following Hurricane Maria, and where respiratory masks were needed during the Southern California Wildfires (Maas et al., 2018 in ITU, 2019). Google has also created a Crisis Map (google.org/crisismap), still especially focused on the United States, for users to help locate critical emergency information. The maps feature satellite imagery and relevant information such as the weather, flood zones, evacuation routes, shelters and power outages drawing on data from the United States National Hurricane Center and weather.com (ITU, 2019).

17 The Internet of Things (IoT) refers to a system of interrelated, internet-connected objects that are able to collect and transfer data over a wireless network without human intervention, available at https://www.aeris.com/what-is-iot/, cited August 5, 2020.

water levels in river basins. These types of technologies can also provide for timely and direct sharing of information with the public using mobile platforms (Izumi et al., 2019b).

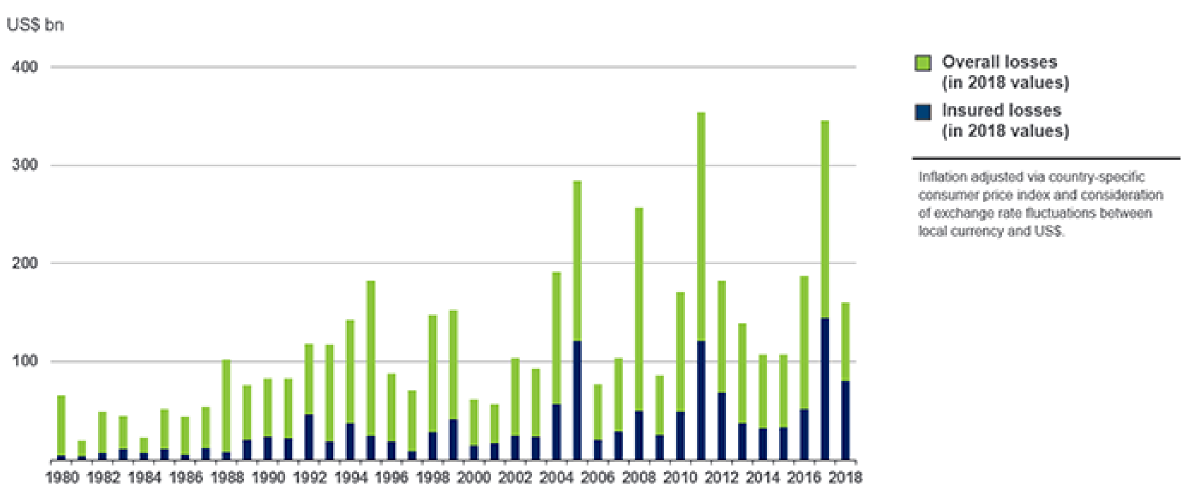
Finally, investments in ICT including accessibility, skills and procedures for online education, telecommuting and teleworking are important components in DRM preparedness. Online learning and working modalities can assist in maintaining and preventing long-term disruptions in the normal functioning of society and business in times of emergency.

Pillar 4. Financial protection

According to the 2019 Global Assessment Report on DRR, "human losses and asset losses relative to gross domestic product tend to be higher in the countries with the least capacity to prepare, finance and respond to disasters and climate change, such as in most SIDS" (UNDRR, 2019, p. vi). Against this backdrop, this pillar attempts to create strategies to protect governments, businesses and households from the economic impacts of disasters. Financial protection involves the strengthening of macroeconomic policies which may be evidenced through various instruments such as risk transfer mechanisms, contingent lines of credit and use of national funds for DRM. Additional aspects that require focus include compensation programmes for vulnerable and affected populations, identification of uninsurable segments of the economy, transfer mechanisms to support local governments, and the encouragement of public and private risk reduction (ECLAC, 2017a, p.5).

Although it is one of the most important instruments available in terms of ex-ante disaster risk financing, insurance uptake by private actors at the community level globally is still low when compared to the overall losses caused by disasters (see Figure 1).

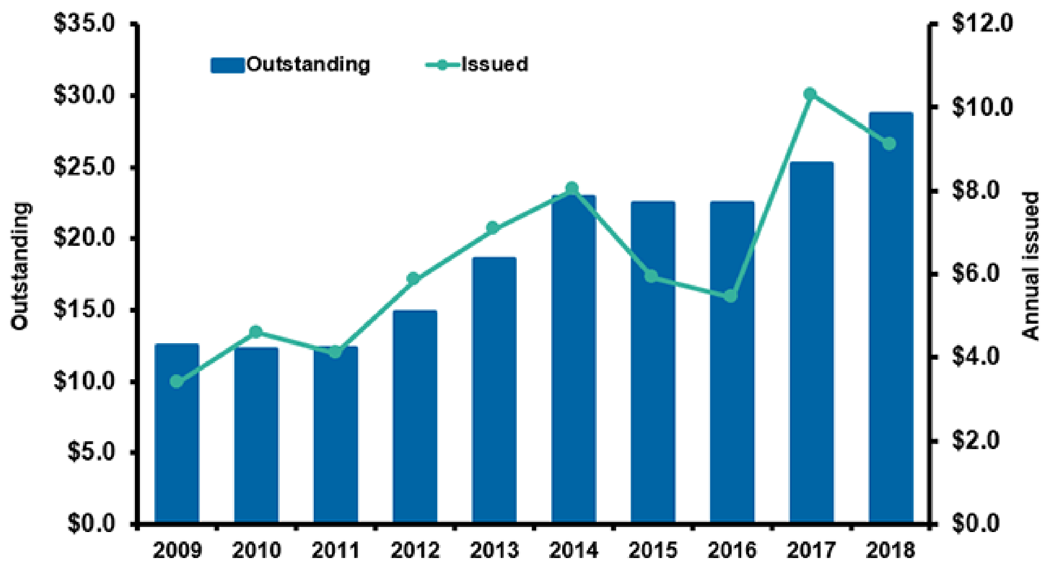
Figure 1
World Natural Catastrophes by Overall and Insured Losses, 1980–2018
(US Dollars billions)



Source: © 2019 Munich Re, Geo Risks Research, NatCatSERVICE. As of March 2019.

Other emerging instruments to finance disaster risk are catastrophe bonds (CAT) and resilience bonds. CAT bonds have become increasingly popular as they pay high interest rates and allow for the diversification of an investor's portfolio without being correlated with other economic risks (see Figure 2). Resilience bonds are designed to fund risk reduction projects via a resilience rebate that turns avoided losses into a revenue stream. By design, they provide a dual application of indemnification with risk reduction measures, as they require a better understanding of risk to be priced (Izumi et al., 2019b). Other instruments are weather-derivatives and weather-index insurance, that stem their values from weather-related variables such as temperature, rainfall, snowfall, frost and wind. These instruments are not commonly used in the Caribbean. They have however been issued by financial institutions in Europe and North America to clients such as energy, agriculture and construction companies. Unlike conventional insurance, there is no loss-adjustment process, therefore settlements are usually quicker once the parameter outlined in the contract is met.

Figure 2
Catastrophe Bonds, Risk Capital Outstanding and Annual Issued, 2009-2018
(US Dollars billions)



Source: GC Securities, a division of MMC Securities Corp., a registered broker-dealer, member FINRA/SIPC, and Guy Carpenter.

Using digital technologies to fundraise for disaster relief victims also offers an alternative way of financing emergency by private agents. Relief agencies, such Habitat for Humanity and UNICEF have begun accepting donations in cryptocurrencies such as Bitcoin. Mobile money has also been a valuable tool for financial inclusion in many countries and has proven to be a simple way for friends, family and relief organizations to transfer funds to those affected by disasters. Companies such as Sikka (https://www.sikka.me/), for example, assist financially marginalized communities to access funds in times of emergencies, whereas Helperbit (https://app.helperbit.com/about) offers parametric peer-to-peer insurance services and donation systems (Fast, L. and Coppi, G, 2019). Another available innovative financial approach is Forecast-based Financing (FbF), which enables access to humanitarian funding for early action based on in-depth forecast information and risk analysis. This instrument enables humanitarian agencies to scale-up preparedness when risk is elevated (Red Cross, 2016). Lastly, Big Data analytics[18] hold enormous potential for crisis management in terms of finance. For example, information on financial transactions allow countries to monitor economic activity during and after a disaster to improve targeting the support.

[18] Big data analytics is the process of examining large and varied data sets to uncover information such as hidden patterns, unknown correlations, trends, associations and behavioural patterns.

The demand for 'shock-responsive', 'disaster-smart' and 'adaptive' social protection systems is also on the rise. These systems aim to guarantee safety nets to provide livelihood support in times of crises by guaranteeing a regular income, rather than just focus on transfers of food or cash to affected communities after a disaster has occurred. Governments are also able to respond quicker to crises utilizing their existing social payment systems and databases of beneficiaries rather than having to establish ad-hoc new ones. Many countries therefore are seeking to adjust their social payment systems to be more DRR and/or climate sensitive (Data-pop Alliance, 2015).

Pillar 5. Resilient recovery

Post-disaster recovery processes represent an ideal opportunity to assess and review existing development plans, build back better, and improve future resilience. As such, resilient recovery is a combination of structural and non-structural measures and processes that must respond not only to the hazard that caused the disaster, but to any potential hazard to which the country or community is exposed (ECLAC, 2017). As an example of non-structural measure, post-disaster assessments are pivotal to resilient recovery as they provide useful inputs for updating territorial planning, financial quantification of risk and the incorporation of resilience and disaster preparedness elements into regional public policies. One of the seven global targets of the Sendai Framework for DRR is to substantially reduce disaster damage to critical infrastructure and disruption of basic services. This will also include structural measures, providing for reduce risk to health and educational facilities. Examples of global initiatives to support this goal are the UNDRR's "Making Cities Resilient" Campaign and the "One Million Safe Schools and Hospitals", with both underscoring the need for disaster-proofing public services and associated infrastructure.

The recent COVID-19 pandemic highlighted the urgencies to also incorporate pandemic threats to regional and national risk reduction strategies. In this regard, strengthening health systems, increasing the understanding of potential health threats, community-level preparedness and response for health-related emergency risks, and a global governance model to foster collaboration in planning and response to such events will have to be included in future national, regional and global discussions and strategies for a multi-risk approach to disasters.

In the Caribbean subregion resilient recovery plans and programmes are already aimed at avoiding reproduction of risk conditions and guaranteeing a quick return to normalcy after a disaster has occurred. In support of these actions innovative actions of working collaboratively as well as tools, data collection and management methods, risk communication and knowledge sharing approaches will be needed to achieve progress in reducing risk and exposure. For example, the potential need to rebuild entire settlements post-disaster may demand the relocation of communities, redesigning infrastructure, especially public infrastructure, and strengthening environmental restoration as nature-based protective barriers.

II. The Caribbean context

This chapter will analyse the situation in the Caribbean subregion related to two variables: (a) disaster vulnerability, and (b) the status of technology and innovation strategies and recent developments.

In order to fully appreciate the importance of investing in more efficient and cost-effective mechanisms for the management of disasters in the Caribbean subregion, it is important to assess the extent of the social, environmental and economic impacts of such events. The data presented in the following section demonstrate that the human and economic costs of disasters pose a significant challenge for many countries in the region and that this high cost can retard or reverse years of socio-economic gains. The section also highlights the challenges faced by many Caribbean countries in the design and application of policies and strategies for technology and innovation in DRM in the Caribbean.

Assessment of the extent of the social, environmental and economic impacts of disasters are requirements for more efficient, sustainable and cost-effective disaster risk management in the Caribbean subregion. According to data collected from the EM-DAT platform[19], the average number of disasters per decade has increased significantly since the 1970s in the Caribbean subregion, as have the number of affected population and the magnitude of the damage suffered. The recurrence of natural threats and population concentrated in coastal areas makes the Caribbean one of the regions with the highest incidence of disasters in the world (ECLAC, 2019).

It is estimated that 84 per cent of the total population of the Caribbean lives in coastal areas with crucial infrastructure near the sea, which exacerbates exposure to potential threats in the region (Mycoo and Donovan, 2017). Between 1970 and 2019, 543 disasters took place in the Caribbean, 92 per cent of which were caused by meteorological, hydrological or climatic phenomena such as storms, tropical

[19] EM-DAT contains basic data on the occurrence and effects of more than 22.000 disasters worldwide from 1900 to the present. The database is compiled from several sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. This database defines a disaster as a situation in which at least one of these four conditions occurred: a) ten or more deaths; (b) one hundred or more people affected; (c) a state of emergency declared; (d) a call for international assistance made.

cyclones and floods.[20] During this period, total damage[21] in the Caribbean amounted to 161 billion dollars.[22] The damage of climate-related disasters is substantial, 94 percent. In seven years, 1995, 1998, 2004, 2010, 2016, 2017 and 2019, the Caribbean suffered more than five billion dollars in damages. These seven years witnessed the destruction of 83.2 per cent of the assets impacted since 1970. The highest value was reached in 2017, which witnessed damages worth 84 billion dollars (ECLAC, 2019b; ECLAC, IDB, PAHO, 2020). Furthermore, in most Caribbean SIDS, economic activities close to the coast such as tourism, fisheries and maritime trade, constitute a significant part of the region's GDP. High impact events such as the 2017 hurricane season and Hurricane Dorian in 2019 in the Bahamas imply a recovery period of at least four years to return to pre-disaster activity levels (ECLAC, IDB, PAHO, 2020). The damage profile of the nine hurricane disaster assessments that ECLAC has conducted between 2015-2019 shows that the most affected sectors in the region have been tourism and housing. Disasters directly affected this main economic activity and largest employer for most countries of the region, and destroyed or damaged essential infrastructure (ECLAC, 2019b; ECLAC, IDB, PAHO, 2020).

This combination of recurrence of disasters and concentration of population and activities in low elevation coastal zones may increase the potential impacts of climate change if projected sea-level rise scenarios occur. In summary, the impact of a disaster in relation to a country's economy is what distinguishes the Caribbean from other regions of the world. For example, in four of the 2017 Atlantic hurricane season assessed disasters,[23] the total cost of the event represented more than 40 per cent of the affected country's GDP, and in two cases it represented more than 100 per cent of the total GDP. External shocks of this magnitude may lead to a loss of social and economic advances that countries achieved over the course of years.

A. Technology and Innovation in the Caribbean: overall trends and current status

In the Caribbean subregion, available data indicates there are opportunities for improvement in the application of technologies and innovation for DRM. However, a thorough assessment of the current status is still challenging due to limited availability of data nationally and regionally. The existing evidence and few studies accessible grouping Caribbean with Latin America suggest that the subregion's levels of innovation and productivity are still quite low (see Figure 3).

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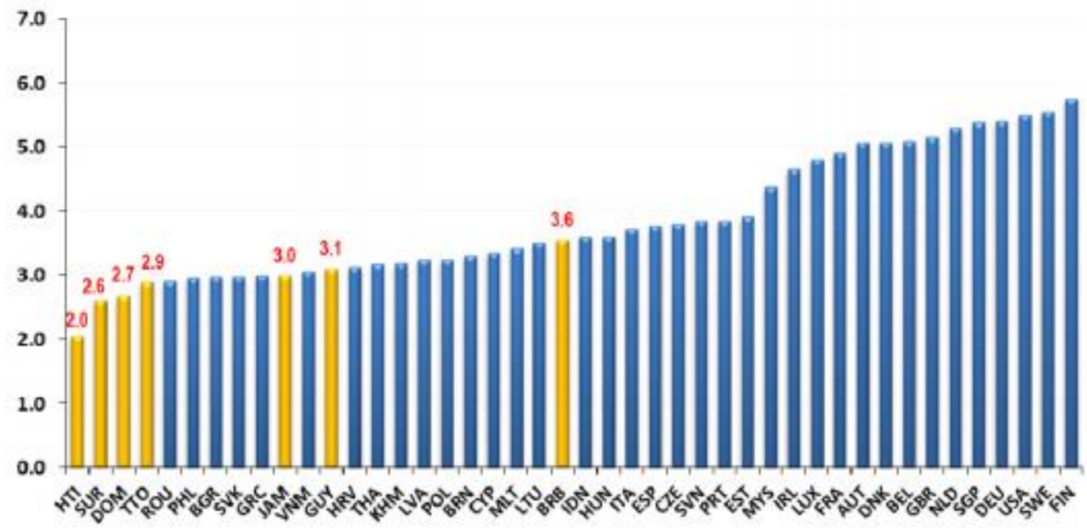
[20] Broadening the geographical perspective, in Latin America and the Caribbean, according to data from the World Risk Index which assesses the exposure and vulnerability of countries to natural hazards, more than 60 per cent of countries present a medium to high risk in the face of disasters. Of these, more than half are at high and very high-risk levels. The concept of World Risk Index refers to the understanding of risk to the danger of natural events, where the risk of disaster is defined as the product of the interaction between physical hazards and the vulnerability of the exposed elements.

[21] Damage represents the value of the partially and totally destroyed assets and the value of the stocks of final and intermediate goods partially and totally destroyed by a disaster, see ECLAC (2014).

[22] The figures of this section are based on EM-DAT (March 2020 version). All monetary figures are in USD of 2019.

[23] In 2017 Hurricane season ECLAC conducted disaster assessment missions in: Anguilla, Turks and Caicos, The Bahamas, Saint Martin and British Virgin Islands.

Figure 3
Global comparison of innovation in individual Caribbean countries based on registered patents
Index 2005 – 2015
(Innovations)



Source: A. Alleyne, T. Lorde, Q. Weekes (2017), A Firm-Level Investigation of Innovation in the Caribbean: A Comparison of Manufacturing and Service Firms with calculations based on World Economic Forum Global Competitiveness Index for 2005–2015, pp3.
HTI:Haiti ; SUR: Surinam; DOM : Dominican Republic; TTO: Trinidad and Tobago; ROU: Romania PHL: Philippines; BGR: Bulgaria; SVK: Slovakia; GRC: Greece; JAM: Jamaica; VNM: Vietnam GUY: Guyana; HRV: Croatia THA: Thailand; KHM: Cambodia; LVA: Latvia; POL: Poland; BRN: CYP: Cyprus; MLT: Malta; LTU: Lithuania; BRB: Barbados; IDN: Indonesia; HUN: Hungary; ITA: Italy; ESP: Spain; CZE: Czech Republic; SVN: Slovenia; PRT: Portugal: Estonia; MYS: Malaysia; IRL: Ireland; LUX: Luxemburg; FRA: France; AUT: Australia; DNK: DNK: Denmark; BEL: Belgium; GBR: United Kingdom; NLD: Nederland; SGP: Singapore; DEU: Germany; USA: United States; SWE: Sweden; FIN: Finland.

The underlying causes for the comparative low innovative performance of the region are also debatable. This can be attributed to such factors as: low R&D intensity; low private sector participation in innovation efforts; limited funding and foreign direct investment for innovation purposes; and a shortage of human capital for innovation. At the national level, government[24] are largely responsible for investments in S&T, R&D and driving technological adoption and adaptation. Further, there are indicators of shortage of researchers resulting that the scientific output is small in comparison to other regions (ECLAC, 2016).

In seeking to address these gaps, in 1988 the CARICOM Secretariat adopted a regional science and technology policy (CARICOM, 2007). Moreover, a Caribbean Council for Science and Technology (CCST) was established in 1980 under the Caribbean Development and Cooperation Committee (CDCC).[25] In 2017, CARICOM through national consultations formulated a regional framework for science and technology. In its Strategic Plan for the Caribbean Community, 2015-2019, it identified among its priorities building resilience in scientific and technological competence to enhance economic, social and environmental capabilities and capacities (ECLAC, 2020). However, in spite of the efforts by governments, multilateral organizations and regional institutions to implement programmes and projects related to science, technology and innovation into the development strategies of the region, the process is still

[24] This is as compared to the private and civil society sectors.
[25] The Caribbean Development and Cooperation Committee was established in 1975, pursuant to ECLAC resolution 358(XVI), to promote and strengthen economic and social cooperation and integration among the countries of the Caribbean and to promote cooperation between them and the countries and integration processes of Latin America and the Caribbean, available at: https://www.cepal.org/en/subsidiary-bodies/caribbean-development-and-cooperation-committee, cited July 1, 2020.

fragmented and constrained by policy shifts, inadequate financial resources, and the challenge of retaining capable staff (ECLAC, 2020). At the national level, only a few countries in the subregion have developed policy frameworks or plans for technology development and innovation, namely Cuba, the Dominican Republic, Jamaica and Trinidad and Tobago. In other countries in the subregion, while there are institutions responsible for establishing and implementing national innovation systems, for the most part no formal strategic plans exist (ECLAC, 2020).

In terms of technology uses for DRM, in one of the very few studies in this regard, Williams and Phillips (2014) highlighted the challenges and constraints related to the usage of ICT in DRM in the subregion. These challenges and constrains included for example: the requirements for adequately skilled human capital; that regional agencies involved in DRM are under-equipped to effectively implement the usage of available ICT in disaster scenarios and there is the need for the establishment and improvements of database of lessons learned amongst member countries. This study further indicated that that data, whenever available, are not always standardized and that there is the requirement for an integrated approach to facilitate data sharing, collaboration and exchange of tools, best practices, knowledge and expertise. Moreover, there is need for greater collaboration among the DRM and ICT practitioners, policy makers, planners, researchers and technology-engaged stakeholders. With respect to ICT infrastructure limitations were identified in terms of information gathering, hazard and vulnerability assessments, early warning alerting, rapid response capability, and the coordination of rehabilitation activities both nationally and with international partners (Williams, R. and Phillips, A, 2014).

III. DRM technology usages and innovative approaches in the Caribbean

The next section will illustrate how technologies and innovative approaches have been applied to each DRM pillars in the Caribbean subregion. It will also identify barriers and make recommendations for addressing these.

A. Risk identification

1. Geospatial analysis

Cognizant of the benefits of geospatial technologies, Caribbean SIDS have sought to develop national capabilities with the assistance of developmental partners. For example, in the context of South-South cooperation, the project "Strengthening of Spatial Data Infrastructure in Member States and Territories of the Association of Caribbean States (ACS)" has benefited 19 countries[26] in the region since 2015. Aligned with the United Nations Initiative on Global Geospatial Information Management, this project has been implemented by the Mexican National Institute of Statistics and Geography with funding from the Mexican Agency for International Development Cooperation and the Government of Chile. The Institute has also been influential in the development of the Caribbean Territorial Information Platform for Disaster Prevention — an online GIS-based multi-risk analysis tool for sharing and managing risk information across the Caribbean (United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), 2018, p. 7-10; ACS, 2016, p.9).

With the aim of further strengthening statistical systems to enable the production of geographic-based data, and in alignment with CARICOM's Regional Strategy for the Development of Statistics, more partnerships have been sought with respect to the development of a foundational

[26] Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Guyana, Haiti, Jamaica, Martinique, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Sint Maarten, Trinidad and Tobago, and Suriname.

geospatial information platform for use in the Caribbean. Towards this end, a memorandum of understanding (MOU) was agreed in March 2019 between CARICOM and the Environmental Systems Research Institute or ESRI (CARICOM, 2019). The Caribbean Geoportal backed by ESRI also offers a significative amount of free data and tools to support the mapping community in the subregion (https://www.caribbeangeoportal.com/pages/about-us).

LiDAR systems[27] have several terrestrial as well as airborne applications and have been increasingly used for surveying and modelling in the Caribbean (CCCCC, 2018). Through improved data capture and analysis, this effectively enhances climate resilience in the Caribbean by supporting evidence-based decision making and policy development. Under the United States Agency for International Development (USAID) Climate Change Adaption Programme, the Caribbean Development Bank (CDB), the Caribbean Community Climate Change Centre (CCCCC) and participating CDB's Borrowing Member Countries (BMCs), these countries have been the recipients of grants for the acquisition of these systems and training of end-users (USAID, 2018). [28] In May 2018, CDB finalised a grant for surveying exercises that would map approximately 10,000 square kilometres utilising these technologies. The Government of the British Virgin Islands has also embarked on LiDAR mapping projects, particularly the Road Town Tortola Catchment Study hydrological project, which will assist in the development of infrastructural designs as well as development and emergency plans in the territory.

Moreover, under the European Union-Global Climate Change Alliance Sustainable Land Management Project specific land information management tools (hardware/software) such a GIS, global navigation satellite system (GNNS), global positioning systems, and other technical instruments as telemetric weather stations, pond level gauges, water testing kits, soil testing kits, etc. were procured, delivered and installed for Member States during 2015, in addition to training provided on utilizing these applications.

In terms of hardware and equipment, ECLAC and Eastern Caribbean Central Bank (ECCB) used drone collected information as a key input of the DaLA[29] of the housing sector after Hurricane Irma in Sint Maarten in 2017 (ECLAC, ECCB, 2017). Similarly, the capabilities of these systems were illustrated in Dominica by the World Food Programme (WFP) after the devastation brought by Hurricane Maria in 2017. Drones were employed to support post-disaster assessments and the resulting aerial images revealed the number of houses affected and roads blocked, allowing for more efficient deployment of resources (WFP, 2018). These technologies were also pivotal to post-disaster surveys funded by the Natural Environment Research Council of the United Kingdom. Field surveys conducted by an expert team of geoscientists, engineers and community resilience specialists relied heavily on drones to capture photographs of inaccessible survey sites. These results informed Dominica's "Build Back Better" strategy and the creation of new guidelines for reducing vulnerability and exposure to hurricane-driven floods (CARICOM, 2018).

Finally, geospatial analysis is not only useful for making pre-disaster sectoral infrastructure baseline, but also in post – disaster assessments. With respect to the former, ECLAC has underscored the importance of having robust and updated baselines of assets and infrastructure in each sector to facilitate DRM activities nationwide. This type of baseline enables post-disaster assessments and the simulation of costs related to disasters. Regarding the latter, ECLAC has used geospatial analysis in recent evaluations

[27] LiDAR technologies can capture topographic and bathymetric data, enabling the production of flood and inundation maps as well as the monitoring of physical changes to the subregion's land and marine environments.

[28] See: https://www.caribank.org/newsroom/news-and-events/lidar-programme-takes-flight-support-cdb-partners.

[29] The Damage and Loss Assessment (DaLA) Methodology was initially developed by the UN Economic Commission for Latin America and the Caribbean (UN-ECLAC) in 1972. The DaLA analysis includes: (i) damage as the replacement value of totally or partially destroyed physical assets; (ii) Losses in the flows of the economy that arise from the temporary absence of the damaged assets; (iii) additional costs, outlays required to produce goods and provide services as a result of the disaster (ECLAC, 2014). The DaLA methodology is comprehensive in scope comprising several sectors including It includes for example, a chapter on the analysis of economic impacts of epidemics. It can also and can be applied in slow-on set disaster disasters such as droughts and the issue of Sargassum in the Caribbean, providing comparable and standard data overtime.

such as the eruption of the Fuego Volcano in Guatemala (ECLAC, 2018c) and that of Hurricane Dorian in the Bahamas (ECLAC, IDB, 2020). In the latter, geospatial analysis was a key input in the evaluation of the housing, tourism, environmental and trade sectors.

2. Hydrometeorological tools

The significance of advance warning of approaching weather-related hazards cannot be overstated. This is of importance to the Caribbean countries given that a large percentage of the population resides in coastal areas. The ability of vulnerable communities to adequately prepare for these threats can drastically reduce casualties through timely planning and evacuation (Izumi et al., 2019). Early warning systems and their attendant inputs are essential tools for managing disaster risks such as floods, storm surges and wind damage. Improvements in forecasting capabilities and accuracy are obtained through the collection of wind data from doppler radar, streamflow and rainfall gauges, as well as automatic weather stations.

Additionally, climate risk information platforms and other decision support tools help guide climate action in sensitive sectors (e.g. agriculture) and prepare for other related hazards such as droughts. Key examples include the Caribbean Climate Online Risk and Adaptation Tool[30] (CCORAL), a collaboration between the Global Water Partnership - Caribbean and CCCCC, as well as the Caribbean Assessment of Regional Drought Tool (CARiDRO).[31]

Bilateral and multilateral developmental assistance has proven instrumental to improving regional hazard monitoring and DRR capabilities. In Jamaica, timely and reliable data collection and management system have strengthened forecasting, flood warning systems and climate resilient planning through the installation and upgrading of real-time streamflow and rainfall gauges under the "Improving Climate Data and Information Management" Project. This falls within the framework of the Pilot Program for Climate Resilience — a funding mechanism under the Climate Investment Funds (CIF) which assisted developing countries to integrate climate resilience into development planning and investment (Government of Jamaica, 2019).

Development cooperation between the Government of Finland and ACS has also reinforced monitoring networks through the "Strengthening Hydro-meteorological Operations and Services in the Caribbean SIDS Project". Implemented by the Finnish Meteorological Institute, Phase 2 of the project has provided national agencies in 16 Caribbean SIDS[32] with training in Aviation Weather Service quality management systems and supported the restoration of weather observation stations in several beneficiary countries (ACS, 2017; Finnish University Partnership for International Development, 2016).

B. Risk Reduction

1. Building codes and resilient structures

Comprehensive, updated and rigorous building codes are essential to protect the population and the physical assets of a country. These building codes must be periodically reviewed to include not only the new challenges posed by extreme events, but also to integrate the newest construction techniques, materials, engineering safety standards, planning and environmental regulations. Performance indicators and historical data of disasters should be used to guide in the revisions and required periodic updates of building codes and other regulatory requirements.

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[30] See http://ccoral.caribbeanclimate.bz/.

[31] See http://caridro.caribbeanclimate.bz/.

[32] Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

Although most countries in the Caribbean subregion have implemented mandatory building codes, there are still challenges in the application of the codes due to limited availability of skilled construction contractors, supervisors and appropriate inspection processes to guarantee continued enforcement of these. This can be further challenging when applied in multi-island States with limited connections between the islands (ECLAC, 2019b). The implementation and enforcement of building codes will require technical and other operative training programs to promote the development of local skills in monitoring and supervising construction works.

Adopting the 'Build Back Better' approach following the devastation visited by Hurricanes Irma and Maria in 2017, United Nations Development Programme (UNDP) has partnered with authorities in Antigua and Barbuda, the British Virgin Islands and Dominica to improve construction standards and support more resilient building code amendments. Antigua and Barbuda has made great strides in prioritising the resilience of its building sector by seeking to implement climate-resilient technologies and interventions in public and community buildings (i.e. disaster services, healthcare, fire services, police, schools and community centres). To illustrate, the proposed "Resilience to hurricanes, floods and droughts in the building sector in Antigua and Barbuda" Project will ensure that critical public service buildings and emergency services can withstand extreme climate events and support the mainstreaming of adaptation into national policies and standards (GCF, 2017).

2. Land-use planning

Existing deficiencies in construction and maintenance practices are exacerbated by absent or incipient territorial planning. To reduce risk, therefore, it is recommended to design zoning systems based on identified risks and exposed communities and physical and environmental assets.

In this regard, the Emerging and Sustainable Cities initiative[33] is worth highlighting. Belize City, for example, has developed several studies as part of this project. These studies include climate change, risks and vulnerability assessments, as well as projections of potentially affected infrastructure and areas of the city. The findings and recommendations of these studies have been implemented in the city's Master Plan and a flood mitigation infrastructure program.[34]

Seismic microzonation has also been used for planning purposes in Trinidad and Tobago. The Ministry of Planning and Development has partnered with the Seismic Research Center of the University of West Indies, which has developed a microzonation analysis of the city of Port of Spain.[35] The Ministry plans to broaden the studies to other locations and to incorporate the data and findings into its land-use planning and regulatory processes.

3. Nuclear technology applied to reducing exposure

In 2016, the International Atomic Energy Agency (IAEA) provided emergency response to Cuba, Dominican Republic, Haiti and Jamaica which were all affected by the outbreak and rapid spread of the Zika virus[36] in the subregion. Nuclear-derived early detection tools and training were made available to Latin American and Caribbean countries to enable rapid identification of cases of the Zika virus. The IAEA's support involved the transfer of technology for virus detection and procurement of related

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[33] For further information: https://www.iadb.org/en/urban-development-and-housing/emerging-and-sustainable-cities-program.

[34] Belize Emerging and Sustainable Cities project summary: https://issuu.com/ciudadesemergentesysostenibles/docs/pub_2015__belizecity_blz_ces_2019.

[35] For project document see: http://uwiseismic.com/Downloads/FAQ_SeismicMicrozonation_.pdf.

[36] Zika virus is a mosquito-borne virus that was first identified in Uganda in 1947 in monkeys. Outbreaks of Zika virus disease have been recorded in Africa, the Americas, Asia and the Pacific. In March 2015, Brazil reported a large outbreak Zika virus infection, and in July 2015, found to be associated with Guillain-Barré syndrome and microcephaly. Outbreaks and evidence of transmission have also appeared throughout the Americas, Africa, and other regions of the world with a total of 86 countries and territories have reported evidence of mosquito-transmitted Zika infection.

machines for affected countries in the region. Additionally, consumables, technical advice and training on how to use the technology were also provided (IAEA, 2018).

4. Participatory approaches and community-based disaster risk reduction

Community participation is necessary when assessing and addressing vulnerabilities, particularly in disaster-prone environments such as the Caribbean subregion. Local stakeholders are best situated to identify and reduce the vulnerability through the identification of local hazards as well as the populations which require the most support, e.g. children, the elderly, and persons with disabilities.

Grassroots campaigns can also have a larger positive impact by creating greater buy-in within communities. These campaigns can be perceived as being "for the people, by the people", rather than as top-down approaches. People-centred participatory approaches increase the long-term sustainability of DRR and DRM programmes by fostering local ownership, promoting risk-informed behaviours, transfers of good-practices, decision making, and building local capacity. They also allow for the continuation of such activities by community stakeholders following the initial intervention of national and international actors (Izumi et al., 2019).

The Caribbean Natural Resources Institute (CANARI) has been influential in this regard. For example, CANARI has developed a toolkit to support civil society organisations in their advocacy for climate change adaptation and DRR using ICTs. This has facilitated participatory vulnerability assessments and adaptation planning utilising ecosystem-based approaches, participatory three-dimensional modeling[37] and a video on participatory approaches.[38]

Civil society is also continuing to contribute to the conservation of biodiversity and sustainable livelihoods in marine protected areas (MPAs) and marine managed areas. An example of such initiative is the CANARI's project on Powering Innovations in Civil Society and Enterprises for Sustainability in the Caribbean (PISCES). With the purpose of mainstreaming resilience with sustain livelihoods, this subregional project focused on "climate proofing" of rural enterprises (e.g. agriculture, fisheries, forestry and tourism) (CANARI, 2019). To ensure national and local-area ownership, the project applied innovative approaches for capacity building including applying combinations of in-country mentoring, coaching and application on ICT tools (CANARI, 2018).

C. Preparedness

1. Emergency communications

Current telecommunications infrastructure is extremely vulnerable to disaster impacts, such as flooding, landslides, and high winds. This is compounded by aging infrastructure, poor maintenance and reinforcement as well as the location of critical telecommunications infrastructure in hazard prone areas. These findings have been a constant theme of the DaLAs conducted by ECLAC in recent years. Given that many Caribbean SIDS can be described as multi-island jurisdictions, the resilience of this sector is pivotal to ensuring the delivery of telecommunications services to all citizens, particularly in the wake of large-scale disasters.

Efforts should therefore be intensified to ensure the resilience of telecommunications infrastructure given the invaluable support they provide in post-disaster situations by facilitating communication, coordination, and intelligence collection (ECLAC, 2017, p.6). Enhanced cooperation including formalized agreements and frameworks between the telecommunications sector and national disaster offices is necessary for more effective disaster response and recovery operations.

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37 3D modelling is a participatory mapping method that integrates indigenous spatial knowledge and spatial data such as elevation of the land and depth of the sea to produce geo-referenced 3D models. It can serve as an interactive way of spatial learning, exchange of information and decision-making.

38 For more details on the project: https://panorama.solutions/en/solution/using-ict-tools-participatory-vulnerability-assessments.

Specialized communications equipment such as satellite telephones and ultra-high frequency radios have been a mainstay of disaster management communications systems in the Caribbean. Moreover, there is common usage of Cell on Wheels (COW) mobile phone towers as temporary solutions to quickly resume mobile services in hard-hit regions. In addition to professionally trained users, there is a sizeable community of amateur radio operators which can operate these emergency communication systems when traditional telephony and data transmission systems are not available.

The usage of amateur radio emergency communications has been actively encouraged by the International Telecommunications Union (ITU) because they have a firm track record of success. This has been bolstered by the ITU's WINLINK project which utilizes amateur radio networks (instead of conventional means of communication such as the internet) as an alternative telecommunication system for use in times of emergencies. WINLINK functions as a "worldwide email service that uses radio pathways...providing its users email with attachments, position reporting, weather and information bulletins" (ITU, 2019). This forms part of a broader partnership between ITU and the Caribbean,[39] being implemented under the "Project for the Use of ICTs in Emergency and Disaster Situations in the Caribbean Region".[40]

2. Early warning systems

The incorporation of innovative technologies into DRR programmes serves to build awareness and participation at the local level, harmonize regional knowledge sharing frameworks as well as strengthen climate monitoring and national preparedness mechanisms (UNDP, 2017). The degree and quality of preparedness are often closely linked to a sound analysis of risks and to existing warning systems. This requirement for early warning was noted in the ECLAC DaLA assessment following on the impacts of Hurricane Joaquin in 2015, a common sentiment from affected persons was that "there was no warning." Hurricane Joaquin, which took a path further south than early predictions had expected, caught the population unprepared. A tropical storm warning for Crooked Island and Acklins was not issued until 5:00 p.m. on the evening before the storm, and, in general, the warning did not reach people soon enough to provide sufficient time for preparation and relocation. In addressing this requirement, ECLAC in its assessment, proposed a revision of existing early warning protocols to consider how warnings could be more effectively propagated in future events. In this regard, the support of telecommunications companies is important since they are key stakeholders in, for example, implementing a "cell broadcasting" technology, used to quickly distribute a warning text message to users of mobile phones within a specified geographic area. This technology was successfully used, for instance, in the Bahamas in 2016. A requirement to implement such schemes, or equivalent technology, should be included in the issuance and renewal of licensing agreements for mobile service providers in The Caribbean. Other key examples include:

- Climate Risk and Early Warning Systems (CREWS) Initiative: As the first regional project under the CREWS initiative, the "Strengthening Resilience and Coping Capacities in the Caribbean through Integrated Early Warning Systems" Project was executed by UNDP and the Disaster Programme of the European Commission Humanitarian Aid Office (DIPECHO), in partnership with the Caribbean Institute for Meteorology and Hydrology, Caribbean Meteorological Organisation and CDEMA. A post-disaster assessment of early warning systems in the Caribbean was conducted following the 2017 hurricane season which highlighted the need for impact-based and gender-sensitive forecasts as well as greater institutional cooperation

[39] Beneficiary countries include Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

[40] See: https://www.itu.int/en/ITU-D/Regional-Presence/Americas/Pages/ACTVTS/AMS-ACTVTS-ET.aspx.

between national meteorological services and disaster management organizations (World Meteorological Organization (WMO), 2019).

- Coral Reef Early Warning System Network: An integrated regional network of climate and biological monitoring stations41 aimed at monitoring the health of coral reefs, this initiative was established by CCCCC in collaboration with the National Oceanic and Atmospheric Administration (NOAA) and funding from the Australian Agency for International Development, the European Union Global Climate Change Alliance (EU-GCCA), and USAID (CCCCC, 2019).

Notably, early warning systems targeting the agricultural sector have been implemented by Guyana's National Agricultural Research and Extension Institute in collaboration with UNDP and the Food and Agriculture Organisation of the United Nations (FAO). Additionally, a gender-responsive approach was utilized for enhancing Guyana's disaster resilience in flood-prone agricultural communities and for revitalizing Dominica's devastated agricultural sector under the "Project to Strengthen Disaster Management Capacity of Women in Guyana and Dominica". Through cooperation between the Government of Japan, UNDP and the United Nations Institute for Training and Research (UNITAR), an early warning system was implemented using a flood modelling approach in the case of Guyana (UNITAR, 2019; UNDP, 2018).

3. Public outreach and social media

Social networking systems have become a common utility of everyday life, along with the usage of computers, smart phones, and tablets with nearly 60 per cent of the population in small islands states in the Caribbean using the internet (World Bank, 2017). In the field of DRM, regional disaster offices indicate that their websites have become the primary mechanism for disseminating pertinent information to the public, with approximately 70 per cent updating their sites at least once per week (Williams, R. and Phillips, A, 2014, p. 35).

Leveraging citizens as sources of real time data is especially useful for crisis mapping. Key examples include OpenStreetMap, which has been used as a basis for several crisis mapping projects, and Ushahidi,[42] which was employed after the 2010 Haiti earthquake where it processed nearly 40,000 individual reports and covered over 4,000 unique events (ECLAC, 2014, p. 21). In the case of Ushahidi, information was drawn from public contributions through several sources, including SMS and email. WebEOC[43] offers another example(http://www.esi911.com/esi/). This is a commercial product that is used by several Caribbean disaster management offices, including the British Virgin Islands, the Cayman Islands, and Trinidad and Tobago, and which serves as a central information hub for the timely management of information related to ongoing events (Williams, R. and Phillips, A, 2014).

Notably, the OECS Commission is already cognizant of the potential impact of web-based and social media application and has entered into an agreement with Facebook Caribbean in June 2019. To improve emergency response among OECS Member States, this agreement allows the OECS to access anonymized location-based information contained within Facebook's Disaster Maps which will "enable relief organisations to concentrate their efforts where they are most needed" (OECS, 2019).

[41] To date, several data buoys and over 50 automatic weather systems have been added to regional climate and weather monitoring networks in Barbados, Belize, Cayman Islands, Dominican Republic, Jamaica, Saint Lucia, and Trinidad and Tobago.

[42] See: https://www.ushahidi.com/.

[43] See: http://www.esi911.com/esi/.

D. Financial Protection

1. Parametric insurance

The Caribbean Catastrophe Risk Insurance Facility Segregated Portfolio Company (CCRIF SPC), created in 2007, is a parametric insurance, offering a country risk-based fund insurance that, unlike indemnity insurance, pays out an agreed sum based on an expected loss resulting from a trigger event. The institution currently provides services to several Caribbean and Central American governments.[44] The model implemented by CCRIF SPC has been further developed in other regions including Africa and the Pacific, where two similar companies were created: the African Risk Capacity (ARC) and the Pacific Catastrophe Risk Insurance Company (PCRIC).

This type of parametric insurance was not designed to cover all damages caused by a disaster, but to give governments access to short-term liquidity mechanisms with a view to dealing with emergency needs following an event, and for reducing budgetary volatility[45]. It was originally designed to deal with catastrophes related to hurricanes and earthquakes in Caribbean countries. This company has continued to innovate, incorporating rain insurance and more recently sector insurance products for activities such as fishing and agriculture. Under the Caribbean Oceans and Aquaculture Sustainability Facility (COAST) initiative, for example, the company is offering a mixed model covering a livelihood protection component (akin to microinsurance) and a tropical cyclone component (sovereign insurance). Likewise, the company plans to offer products for drought and public utilities (CCRIF SPC, 2019).

2. Micro-finance mechanisms and community-based funding

Micro-financing is a positive scheme to allow vulnerable communities, who cannot usually access resources by traditional means, to receive funds and protect livelihoods. These products typically include micro-credit, micro-deposit, and micro-insurance schemes. For example, micro-credit mechanisms can be underwritten by national financial institutions and intermediated by private sector financial institutions which, in turn, offer concessional lines of credit which have the specific aim of increasing uptake and access to climate finance at the community level (ECLAC, 2020). To date however, micro-finance mechanisms have been used at a very low scale in the Caribbean.

The Jamaica's micro-credit model, for example, under its Pilot Project for Climate Resilience, offers loans to rural communities at concessionary rates to implement adaptation activities. Under the support of this Pilot Project, approximately US$17.5 million was allocated to an Adaptation Programme and Financing Mechanism Project by the Climate Investment Funds through the Inter-American Development Bank (IDB) for implementation by the Planning Institute of Jamaica and Ministry of Economic Growth and Job Creation. These national entities provide a Climate Change Adaptation Line of Credit to approved financial institutions (i.e. mutually owned cooperative banks and credit unions) through the Development Bank of Jamaica (Climate Investment Funds, 2018 *in* ECLAC, 2020). Select financial institutions based on their presence in rural communities in the country can provide grants and loans up to a ceiling guaranteed by the funds from the pilot project. To ensure compliance with the terms of these loans, the Development

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44 Caribbean – Anguilla, Antigua and Barbuda, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Sint Maarten, Saint Vincent and the Grenadines, Trinidad and Tobago and Turks and Caicos Islands. Central America – Guatemala, Nicaragua and Panama.

45 The payment generated by this insurance is estimated as follows: first, CCRIF SPC immediately considers the threats for each type of product. This is the speed of the wind and the tidal wave (tropical cyclones) or the movement of the soil (earthquakes) or the volume of rainfall (excess of rain). In each case the information is incorporated into the damage simulation models of the CCRIF SPC which are based on a baseline information where there is a measurement of the physical assets exposed. The simulated damage in the previous point is compared to the minimum level insured. If you overcome, it generates a payment up to the limit of coverage. CCRIF SPC makes payments 14 days after the event. Since its founding, 38 payments have been generated for a total amount of 138.8 million dollars.

Bank of Jamaica consistently monitors the portfolios of approved financial institutions (Climate Investment Funds, 2018 *in* ECLAC, 2020).

Micro-insurance initiatives also play an important role at the community and at individual levels, since these risk transfer mechanisms assist farmers, fisherfolk, and other small enterprises to deal with the impacts of floods, droughts and other hazards (Izumi et al., 2019). Against this backdrop, the Climate Risk Adaptation and Insurance in the Caribbean (CRAIC) Project was launched — an initiative geared at developing and increasing the reach of livelihood protection policies in the region and providing loan portfolio cover to risk-exposed lending institutions (Munich Climate Insurance Initiative, 2019 in ECLAC 2020). The project is funded by Germany's Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety under its International Climate Initiative and implemented by the Munich Climate Insurance Initiative (hosted at the United Nations University's Institute for Environment and Human Security) and was developed in collaboration with CCRIF-SPC, DHI, the ILO Impact Insurance Facility, and Munich Re (CCRIF-SPC, 2018). Under Phase One and Two of the CRAIC project, two index-based micro-insurance products were launched in Grenada, Jamaica and Saint Lucia, with planned expansion to Belize and Trinidad and Tobago.

Development assistance and funding can also be channeled through community-based actors and stakeholders who have a first-hand understanding of the fragility of their respective communities. In this regard, several such initiatives in funding community resilience programmes exist, for example:

- Community DRR Fund: Accessible to NGOs and community-based organisations in borrowing member countries of the CDB, this was established with grant financing from Canada's Department of Foreign Affairs, Trade and Development and DFID (https://cdrrf.caribank.org/).
- Canada Caribbean DRM Fund: Supporting small scale projects initiated by voluntary agencies and community groups, grants between CDN$25,000 to CDN$50,000 are available for gender-sensitive projects with tangible DRR benefits for low-income and rural communities (https://www.cdema.org/ccdrm-fund).
- Caribbean Catastrophe Risk Insurance Facility (CCRIF) Small Grants Programme: Awards of US$5,000 to US$25,000 are granted to NGOs, community-based organisations, charities, national disaster coordinating bodies or universities in CCRIF and/or CARICOM member countries (https://www.ccrif.org/content/programmes/small-grants-programme).
- Global Environmental Facility (GEF) Small Grants Programme: Supporting community-driven and civil society-led initiatives, the programme awards grants up to a maximum of US$50,000 (https://sgp.undp.org/).

3. Post-disaster mobile payments

Digital innovation can play a crucial role in the preparedness and response to disasters. The digitalization of finance provides new avenues for inclusion of vulnerable populations without access to commercial banking services. This also could increase financial literacy and contribute to overall poverty alleviation in developing countries (United Nations, 2018, p. 81). Mobile payments are one such emerging technology, functioning as electronic currency stored in an e-wallet on mobile phones. First introduced in Kenya as M-PESA in 2007, it was developed as an alternative means for the unbanked population to have access to financial services (World Bank, 2017).

Its application in post-disaster situations can drastically improve the financial stability of affected persons, especially in rural areas, where traditional banking infrastructure is limited or has been devastated. In the aftermath of a disaster, mobile payments can also facilitate early recovery investments, the purchase of personal necessities as well as donations and cash-based interventions being executed by international aid agencies (Izumi et al., 2019).

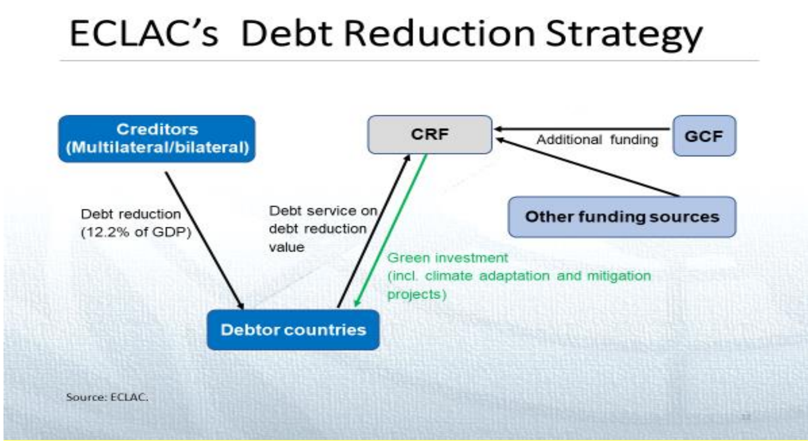
The introduction of mobile payments following the 2010 earthquake in Haiti is an important illustration of innovation in rapid-onset emergencies. Within six months of the event, USAID and the Gates Foundation announced a Challenge Fund Competition to encourage the launch of mobile money services to "expedite the delivery of cash assistance to victims of the country's devastating earthquake by humanitarian agencies" (ODI, 2012, p.19). In collaboration with two mobile network providers and local banks[46], these services were successfully integrated with the work of several relief agencies and facilitated mobile payments for cash for work, food assistance and pension programmes (ibid.).

4. ECLAC Debt for Climate Adaptation Swap Initiative

The Debt for Climate Adaptation Swap Initiative spearheaded by ECLAC aims to tackle two pressing issues in the Caribbean: debt and vulnerability. As part of a larger scheme of "debt-for-environment swaps" (DFES), it aims to provide opportunities for raising capital to address environmental and other policy challenges. It is an innovative strategy that involves harnessing concessionary flows to transform the debt of the region into a source of investment in resilience building and related projects, an attribute which differentiates it from standard debt reduction mechanisms.

The Initiative proposes the creation of a Caribbean Resilience Fund (CRF) whose major function will be to channel pledged climate funds and other contributions to gradually write down the Caribbean's debt stock[47]. This will be contingent on debtors agreeing to make annual payments into the fund in an amount equal to the discounted debt service payments (Alleyne, 2018). It should be housed at a credible regional institution, preferably a bank with the capacity to administer the resources. The CRF will be capitalized, initially, through a combination of contributions from international financial institutions, bilateral donors and the GCF; and subsequently from the haircut values negotiated through the swap and discounted debt repayments on the part of the beneficiary Caribbean economies (Figure 4).

Diagram 1
Schematic representation of ECLAC's Debt Reduction Strategy



Source: ECLAC (2020).

[46] The first service, Tcho Mobile, was developed in collaboration with Digicel and Scotia Bank (re-launched in 2015 as MonCash). This was closely followed by T-Cash — launched by Voilà and Unibank in 2010.

[47] This initiative was endorsed by the Caribbean Development and Cooperation Committee in 2016 by virtue of resolution 93 (XXVI): Advancing a debt relief initiative for the Caribbean. A task force to advance the ECLAC Debt for Climate Adaptation Swap Initiative has since been established with representatives from national agencies and key subregional institutions such as the Caribbean Community Climate Change Centre, CARICOM, the Eastern Caribbean Central Bank and OECS. While further negotiations are required amongst governments, creditors and climate donors to particularise each element of this mechanism, the initiative has been championed and well- received at regional forums and several international engagements involving ECLAC. Through advocacy and increased technical cooperation among member States, ECLAC continues to mature the proposal from the conceptual design phase to a bankable proposal for submission to the donors. Please see ECLAC (2018), Report on the Second Meeting of the Task Force to Advance the Proposed ECLAC Debt for Climate Adaptation Swap Initiative, LC/CAR/2018/3, Santiago, p. 4.

5. Shock responsive social protection systems

Social protection systems are a fundamental instrument for Caribbean countries to prepare, respond and mitigate the impact of disasters. While most countries in the region have DRM strategies in place, these have yet to be mainstreamed into all sectors, including in social protection systems (Barca et al., 2019). Disasters impact on social protection systems in two different ways: by expanding the need for social protection for many individuals in a short period of time and by undermining the capacity of the existing systems to deliver due to resource limitations and affected infrastructure. Governments can use different instruments to apply the existing social protection mechanisms to shock response such as: increasing a benefit value or duration (vertical expansion), temporarily extending support to new households (horizontal expansion) or using the administrative capacity to deliver an aligned emergency response (piggybacking).

In the Caribbean subregion, the use of national social protection to prepare for and respond to shocks is still emerging. As an example of mainstreaming DRM strategies into national social protection legislation, Jamaica's Social Protection Strategy discusses social protection's role in social risk management, including risks related to 'environmental conditions' and 'natural events such as disasters', and acknowledges social protection's 'preventive' and 'mitigative' functions, including for 'disaster preparedness' (Government of Jamaica, 2014 in Barca et al., 2019).). Anguilla's Social Protection Policy, Action Plan and Framework also encompasses a strong focus on 'integrating social protection into climate change adaptation planning and programming' and 'disaster preparedness and response'. Trinidad and Tobago's 2017–2022 National Social Mitigation Plan also recognises the balance between assisting targeted populations to cope with shocks while maintaining a focus on national development goals and resilience building (Barca et al., 2019).

Social protection systems have also been used on many occasions as a channel to provide support to the affected population. Dominica, for example, leveraged the existing social protection systems to temporarily increase the value of transfers to existing beneficiaries after Hurricane Maria. The 'Emergency Cash Transfer', with the support of United Nations Children's Fund (UNICEF) and the World Food Programme WFP, had a transfer value of US$90 per household per month, with a top-up of US$50 per child, up to three children also including families not originally covered by the service, but that were severely affected by the hurricane (Government of Dominica et al., 2018 in Barca et al., 2019). In the British Virgin Islands, a Joint Cash Platform was developed by British Virgin Islands Red Cross/British Red Cross and Catholic Relief Services/Caritas Antilles, in coordination with the Ministry of Health and Social Development and the Social Development Department (SDD), after Hurricanes Irma and Maria. The platform was used to transfer over US$3.2 million to 1,076 vulnerable hurricane-affected households between December 2017 and January 2018. Following Hurricane Ivan in 2004, the NIS in Grenada provided unemployment insurance to registered members through the Temporary Employment Programme up to a maximum of six months (Barca et al., 2019).

CDEMA's CDM Strategy and Results Framework (2014–2024) includes the 'Caribbean Pathway to Resilience' framework[48], in which the Pillar 1 is Social Protection for the Marginal and Most Vulnerable. CDEMA's strategic document recognises the need to strengthen and leverage national social protection as a mean to broaden the support for the most vulnerable in the face of existing hazards (Barca et al., 2019). Moreover, ECLAC's Third Meeting of the Regional Conference on Social Development in Latin America and the Caribbean (2019) approved the proposal for a regional agenda for inclusive social development, based on the following axes: universal and comprehensive social protection systems; policies for social and labor inclusion; a strengthened social institutional framework; and regional cooperation and integration to advance towards inclusive social development and to achieve sustainable development.[49]

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48 The other pillars of the framework are: I. Social Protection for the Marginal and Most Vulnerable II. Safeguarding Infrastructure III. Enhancing Economic Opportunity IV. Environmental Protection V. Operational Readiness.

49 Third session of the Regional Conference on Social Development in Latin America and the Caribbean XI; Ministerial Forum for Development in Latin America and the Caribbean Mexico City, 1–3 October 2019; see document at: https://crds.cepal.org/3/sites/crds3/files/19-00633_cds.3_proposed_regional_agenda.pdf.

E. Resilient Recovery

1. Health facilities and schools' resilience

Disaster resilience in the health sector is particularly crucial as these types of public infrastructure are central to emergency response. Resilient infrastructures in the education sector are also required as these buildings often serve as shelters to vulnerable communities during and after disasters. As such, hard and soft investments as well as "smart" construction and retrofitting for disaster resilience must be mainstreamed into development planning processes, along with the integration of DRM into project preparation and evaluation cycles of public investment portfolios to accomplish this goal.

Health facilities are a critical element in emergency response and must be fully operative during and after a disaster. An affected population is especially vulnerable when local and national health systems are unable to deliver public services. Recognising this, the Pan-American Health Organisation (PAHO) developed a Smart Hospital Toolkit to increase structural and operational safety within this sector and guide health officials and hospital administrators in achieving smart health care facilities. This initiative establishes an integrated and innovative approach to building and retrofitting health care facilities to ensure that they are environmentally friendly and disaster resilient (PAHO, 2017).

Through the application of the Hospital Safety Index, green checklists, cost-benefit analyses and baseline assessment tools, a number of appropriate interventions can be identified and implemented with the aim of: (i) reducing energy consumption and greenhouse gas (GHG) emissions through the installation of photovoltaic systems (also critical in the event of power outages); (ii) improving air quality; (iii) enhancing physical access and safety conditions through sustainable construction practices; and (iv) improving access to potable water through the installation of rainwater capturing systems. With financial assistance from the United Kingdom Department for International Development (DFID), Phase Two of the Smart Hospitals Project is being implemented in seven countries: Belize, Dominica, Grenada, Guyana, Jamaica, Saint Lucia, and Saint Vincent and the Grenadines (PAHO, 2019).

School safety and disaster resilience is another key priority area among Caribbean SIDS. The Caribbean Safe Schools Initiative is a prime example of this, focusing on disaster-resilient infrastructure, school disaster management, and DRR and resilience education across the region. This initiative served as the Caribbean's contribution to the Worldwide Initiative on Safe Schools — a programme developed by key partners of the Global Alliance for DRR and Resilience in the Education Sector (CDEMA, 2017). In April 2019, five additional countries adopted the Antigua and Barbuda Declaration on School Safety during the Second Caribbean Safe School Ministerial Forum, bringing the total number of regional participants to 17 countries[50] (CARICOM, 2019).

As part of this initiative, CDEMA formulated a Model Safe School Programme toolkit for implementation in CDB borrowing member countries with funding from the ACP-EU-CDB Natural DRM in CARIFORUM Countries Programme. The toolkit has been used to develop National Safe School Policies and provides regional governments with technical support and tools for assessing building conditions and compliance with school safety standards, conducting hazard assessments and green assessments as well as developing gender-inclusive policies on school safety. In 2017, six countries undertook training within the Model Safe School Programme. These countries were: Antigua and Barbuda, Guyana, Montserrat, Saint Kitts and Nevis, Saint Lucia, and Turks and Caicos Islands (UNDRR, 2019).

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[50] Antigua and Barbuda, Anguilla, British Virgin Islands, Curaçao, Dominica, Dominican Republic, Cuba, Grenada, Guyana, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Sint Maarten, Suriname, and Turks and Caicos Islands.

2. Water resilience

A robust Water, Sanitation and Hygiene (WASH) response is fundamental to limiting the spread of disease in post-disaster situations. Water utilities are particularly vulnerable to the threats of water borne diseases, and their disruption may have harmful consequences if disaster risk is not timely and adequately managed. Droughts and other climate change-related hazards also have acute effects on the availability and potability of water supplies. In view of this, the Caribbean requires innovative approaches for increasing its resilience to severe weather impacts and climate variability.

Due to changing rainfall patterns, increasing salinity, groundwater pollution and other freshwater scarcity problems, de-salinization and rainwater harvesting is expected to be increasingly indispensable in building the Caribbean's future water resilience. The resilience of this sector is also of direct relevance to agricultural production (upon which many Caribbean economies depend), tourism, and to controlling potential health impacts and vector-borne diseases in the event of a disaster (ECLAC,2015).

While desalination technologies have been a mainstay in several countries in the Caribbean (e.g. Aruba, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cayman Islands, Curaçao, Grenada, Saint Martin, and Trinidad and Tobago), the centralised nature of these facilities also make them vulnerable to disasters; as was the case in Barbuda in 2017 following the passage of Hurricane Irma (CDB, 2017). Conversely, rainwater harvesting systems exhibit a higher level of decentralisation, thus lessening the risk of national disruption of water availability.

Rainwater harvesting systems are simple, cost-effective and can easily be retrofitted into existing public and private buildings. Approximately 500,000 persons across the Caribbean are either fully or partially dependent on this technology. Water-stressed countries continue to embrace rainwater harvesting to address their water needs. While rainwater harvesting is actively promoted in Caribbean SIDS such as Barbados, Bermuda, Grenada and the U.S. Virgin Islands, initiatives such as the Global Water Partnership's Caribbean Rainwater Toolbox[51] have been launched to increase its proliferation, re-establish rainwater harvesting culture in the Caribbean (Dempewolf et al., 2015).

Key successes in improving water resilience through rainwater harvesting and other adaptive measures have been observed in Barbados. The importance of conservation, adaptation to climate variability and decentralisation of water sources has been promoted under the GCF's "Water Sector Resilience Nexus for Sustainability in Barbados" Project. Implemented by CCCCC, the programme will support climate smart development and water sector resilience through targeted policies and legislation, increasing rainwater harvesting, building technical capacity, in addition to increasing public awareness and resilience to severe weather impacts (GCF, 2018; CCCCC, 2019).

3. Data for evidence-based planning

Data-driven analysis is fundamental to implementing, monitoring and measuring the impact of resilience-building policies and programmes. The development of appropriate methodologies for ex-ante and ex-post assessments and the sharing of good practices are key in carrying out assessments on national risk and risk management capabilities. This requires improving the recording of loss and damage data through robust systems, models and methodologies.

ECLAC has emphasized the importance of high-quality data, statistics, ICT and data management platforms as tools for the implementation of national sustainable development agendas — including when developing ex-ante and ex-post measures for DRM. Moreover, risk assessments and other pre- and post-disaster analytics need to be quantified and understood Ministries of Finance when establishing

[51] See http://www.caribbeanrainwaterharvestingtoolbox.com/.

resilience-oriented strategies that combine investments in risk prevention and risk transfer, with resources for emergency response, recovery and reconstruction (ECLAC, 2017a, p.5).

Data availability and access is of utmost importance in the Caribbean. However, having a culture of just in time data sharing can be a challenge because of fragmented physical and social geography of the Caribbean SIDS. In recognising the importance of pre- and post- disaster data to the Caribbean region, the sections following provide case examples and mechanisms for supporting their collection, analysis and accessibility:

(a) Pre-disaster assessments

Systematic and long-term data is required for comprehensive assessment of damage to assets, systems and sectors following in the impact of a disaster. The World Meteorological Organisation guidelines (2007) have further guided that data collection should be repeated in the same areas in order to detect trends that cannot be seen a few hours or days after the event and to monitor the rehabilitation and recovery processes. A standardised reporting system, similar to the PDNA, would provide significant advantages. First, because they will permit comparison between cases across geographic regions and time, it will then be easier to recognise similarities among cases and aspects that are specific to each case. Second, data collected and processed in the same way for key variables will allow practitioners to obtain statistical evidence for some variables that at present are described only in a qualitative way. Third, more comprehensive and comparable reports will permit the building of a body of knowledge on different types of damage to sectors that can support decision-making for a more resilient recovery and to provide data for pre-event modelling (Poljanšek, K., et al. (Eds.), 2017).

In order to mainstream DRM in its development plans, the British Virgin Islands (BVI), for example, has incorporated hazard mitigation requirements within the National Planning Act 2004. The 2004 Act originally required certain developments to undergo environmental impact assessments, the Act was then updated in 2010 to include the necessity of hazard assessment for any kind of development within designated hazardous areas. The Hazard Vulnerability and Risk Assessment includes erosion and drainage concerns. The country has also developed a multi-Hazard Atlas compatible with the National Physical Development Plan. The Department of Disaster Management also coordinates with sectoral departments (such as the Public Works Department and the Town and Country Planning Department) on integrating hazard mitigation in their development plans (Barca et all, 2019). Jamaica has also developed a Disaster Risk Information Platform (DRIP) system for St. Catherine Parish. The platform is an information hub that can be used to access documents, research, and maps related to hazard, risk, and vulnerability information. It comprises four main modules: a) data collection (risk information); b) data management, storage, and publishing; c) search and discovery; and d) visualisation (DRIP Web Map).[52]

(b) Post-disaster assessments

ECLAC has undertaken substantive research and economic assessments of the climate change-related disasters in Caribbean economies and spanning over 40 years. From the 1970s, ECLAC has led more than 100 damage and loss assessments (DaLAs) on the social, environmental and economic effects and impacts of disasters in almost 30 LAC countries (ECLAC, 2017b). In recent years, ECLAC undertook five DaLAs[53] including in the aftermath of Hurricanes Irma and Maria, eruption of Fuego Volcano (Guatemala, 2018) and Hurricane Dorian (Bahamas, 2019).

ECLAC has continued its innovation in this field, publishing a Disaster Assessment Methodology Exercise Guide[54] in 2017 as a follow-up tool to its internationally recognized Handbook for Disaster Assessment, updated in 2014. Since its publication, the Handbook has been used as the basis for disaster

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[52] See: http://apps.licj.org.jm/drip/fa_IR/dataset?tags=community.

[53] Conducted in Anguilla, The Bahamas, British Virgin Islands, Turks and Caicos Islands and Sint Maarten.

[54] The Guide comprises practical exercises and accompanying solutions to estimate the effects and impacts of disasters within the social, infrastructure and productive sectors (add link for accessing document).

training courses in the LAC region. The recipients of this training include disaster management agencies, regional inter-governmental agencies and financial institutions. In addition to training in the assessment of small and medium scale disasters, ECLAC has also assisted the Government of Argentina in the development of an Immediate Response Programme for Floods (ECLAC, 2019a). This level of international acceptance illustrates the relevance, soundness and innovativeness of ECLAC's multi-sectoral approach, as well as the importance of this methodology in strengthening institutional capacities for DRM. In 2019, ECLAC developed an on-line training course of the DaLA methodology. The English version of the course is based on lessons learned and examples of the assessments in the Caribbean sub-region.

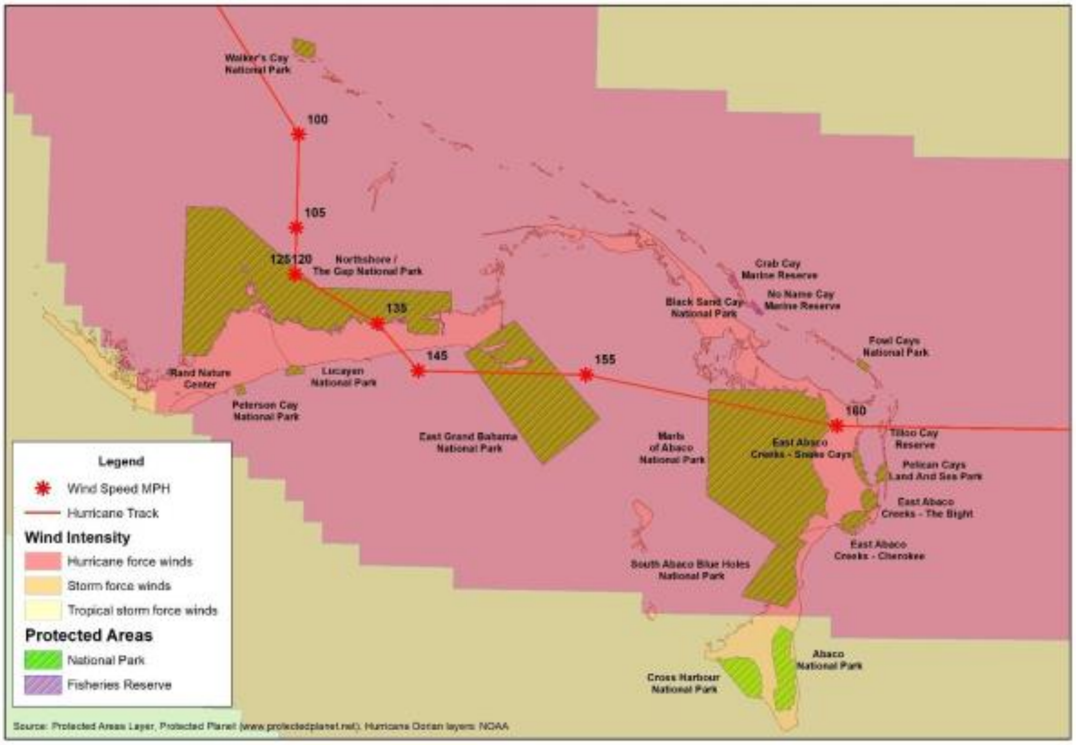
The Post-Disaster Needs Assessment (PDNA) is another methodology for estimating the physical damages, economic losses, recovery costs and population needs following a disaster. Formulated by the UN Development Group, the World Bank and the EU, it harmonises the processes and methods used by these organisations and was designed to "avoid the duplication of efforts, streamline the recovery process and provide an evidence base for resource mobilization" (UNDP, 2019). Governments are often expected to lead the PDNA process and the results are used as a basis for requesting rebuilding support and aid from developmental assistance agencies.

Post and pre-disaster assessments are greatly improved with the use of technology. A combination of Satellite and drone images, for example, combined with advanced statistical models allow for a more comprehensive and detailed analysis of damage and loss, especially in areas where access is difficult. In the latest assessment related to Hurricane Dorian in the Bahamas, satellite imagery and GIS models were combined with statistical modeling to calculate damage in buildings and infrastructure and ecosystems in cases where baseline data was not available and to fill other information gaps (Figure 5 and 6). Most of the satellite imagery used was made freely available through global platforms such as Copernicus, the European Programme for Earth Observation. Similarly, initial analysis of damaged assets was completed through crowdsourcing efforts with the usage of freely available software such as Google Earth Engine (https://earthengine.google.com/).

Image 1
Affected areas Grand Bahama eastern side of the Island

Source: Google Earth, Airbus image (2019).

Map 1
National Parks and Hurricane Dorian Trajectory



Source: Assessment of the Effects and Impacts of Hurricane Dorian in The Bahamas, (ECLAC, 2019).

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

4. Progress in DRM in the Caribbean subregion

The Caribbean subregion in its efforts to promote resilience has been the recipient of funding for innovative projects from several sources and development partners in the field of DRM, benefiting both from an increased international interest in these types of ventures as well as a subregional commitment to including DRM in national plans and strategies. These allowed for the utilization of different innovative approaches and technologies in DRM, see table 2 for examples of some commonly applied tools.

Table 2
Common tools in DRM and usage in the Caribbean subregion

Tools	Geospatial tools	Building techniques and construction standards	Social Media	New insurance models	Eco-system approaches
Disaster phase	Risk identification, reduction, response	Risk reduction, resilient reconstruction	Preparedness	Financial protection	Resilient reconstruction
Complexity	Low to obtain image (from partner institutions and international organizations), high to analyze and interpret.	Medium to implement new construction codes, high to guarantee compliance.	Low to disseminate, high to analyze and interpret	High (to establish sovereignty insurance feasible models and provide access to a larger portion of population for other insurance types)	Depend on the technique

Tools	Geospatial tools	Building techniques and construction standards	Social Media	New insurance models	Eco-system approaches
Stakeholders	Disaster agencies, government, NGOs, International organizations	Governments, private sector	Public, NGOS, government	Banks, Governments private sector	Governments, private sector, NGOs, International organization
Challenges	Access to the data, personnel and tools for data analysis, knowledge platform for sharing.	Availability of materials and funding, training of personnel, knowledge of construction techniques, enforcement of regulations	Access to internet, digital literacy of portion of population, analysis of data produced, regulatory framework for data usage, privacy and protection	Low private insurance penetration, low public asset insurance, accessibility of general population to insurance products	Lack of knowledge of available options, high initial cost, lack of incentive and regulatory framework

Source: authors based on ITU (2019) Disruptive technologies and their use in disaster risk reduction and management.

In the pillar of risk identification, for example, the usage of available geospatial information technologies and hydrometeorological tools has been observed across the subregion, as well as a determination to seek international partnerships to improve the systems in place. In terms of risk reduction, planning has been increasingly based on mapping of hazards and identification of exposed assets, although it would be beneficial to have a more comprehensive approach considering multisectoral aspects such as, for example, water and sewerage management, environmental management, infrastructure development, flood mitigation besides zoning and land use. In preparedness, we observe projects in both, application of new technologies for the identification and communication of hazards as well as the education and sensitization efforts of the population. Still, it is important to foster networks of public and private entities, communities, international and regional organizations to strengthen coordination and further amplify the participatory approach.

The region was a pioneer in applying parametric insurance as a financial protection instrument. However, normal household and business insurance penetration is lacking, as is the application of more diversified instruments to secure stable funding sources. Resilient planning must consider a financial strategy to protect public sector assets and generate incentives for the private sector to protect their own. In terms of resilient recovery, efforts to systematize and collect post-disaster data are laudable. As are plans that guarantee that educational and health sectors facilities withstand extreme climate events. The resilient reconstruction process, however, should not only be aimed at rebuilding strong infrastructure, but also seeking to guarantee access to basic services and livelihoods, which may require new and creative approaches to redesigning existing social structures such as energy production frameworks and social protection systems.

IV. Conclusion and recommendations

While the scale of some disasters is often unpredictable, their impacts can be mitigated or partially prevented through a systematic evaluation of associated risks. Other contributing factors are the use of appropriate tools, technical assessments and effective early warning systems to decrease exposure and protect vulnerable populations. The hurricane season of 2017 and most recently Hurricane Dorian in the Bahamas (2019) underscored the vulnerability of the Caribbean and exposed the need for enhanced DRM regulatory frameworks, improved development planning processes and institutional risk management structures in Caribbean economies. This requires approaches that are cross-cutting, multi-sectoral and integrated, and which also consider the multi-scale environmental, governmental and socio-economic conditions which shape vulnerability and capacity to respond to hazards.

The application of technology and innovative approaches for disaster and risk management has globally contributed to preparedness and response to major crises and resulted in a reduction of the toll on human lives and economic assets. As one of the most affected subregions in the world, the Caribbean has been part of this global trend. However, some challenges are still very real:

- DRM organizations often are limited in accessing the required tools and infrastructure to adopt and use existing available technologies.
- There is Limited connection and or access to the global networks of expertise and science in DRM.
- Difficulties in collecting and sharing data and information needed for DRM nationally and at a regional level remain. Data usually comes from a wide variety of sources that are often not shared or integrated in a way that facilitates timely and accurate decision-making in a disaster situation. This is further complicated by the differences in standards used for data collection, recording and storage. Some countries lack historical records (or do not have this data available in electronic format) of hazards and the quality of the data may vary, which makes comparison difficult.
- There are limitations in human resources to successfully deploy and utilize certain technologies. Many of these skill sets and supporting resources are in short supply in the Caribbean. For example, there is a need for skilled human technicians, especially in the field

on DRM, to deploy, operate and maintain these instruments for use of GIS, drones, robots and big data analytics (Data-Pop 2015).

- Financial barriers, often resulting from as lack of fiscal space and inability to access the major global sources of funding for DRM remain a serious challenge.

In line with these challenges aligned with global trends on technology application and innovative approaches to DRM in the subregion, the following recommendations are proposed:

Strengthening STI capabilities and connection with DRM policies and approaches.

Providing an enabling policy environment is the first step towards integrating technologies and innovative approaches into DRM. This will also allow for enhancing accessibility and bridging the gap between the fields of TI and DRM by ensuring on-going cooperation. Improving national and subregional systems of innovation and technological development strategies is crucial, as countries tend to place a low priority on R&D, a situation which is aggravated by lack of overall investment in DRM. There is also a need for improved coordination among research institutions, DRM agencies, technology providers and policymakers nationally, regionally and globally. This coordinated framework can serve to reduce duplicating activities, sharing of best practices and identifying knowledge gaps and/or developing strategies to prioritize required areas of research. Promoting public-private partnerships can help to share costs and access best availability of technologies.

Cultivating local skills is also required to apply existing and future technologies and nurture local and other innovative approaches. This will necessitate the creation of DRM structures for training, capacity development, information gathering and sharing involving practitioners, end-users, trainers, scientists and researchers.

Finally, there is a need to reflect on mechanisms for linking solutions proposed by research with the needs of practitioners, in order to produce timelier and context-appropriate results. This shall be based on an adequate assessment of needs, analysis of results of existing measures and evaluation of countries' technological readiness. This combination of existing global technologies and indigenous solutions, as well as integration of local knowledge into the decision-making process, should support the adjustment and approaches to the meet the need for localised application requirements

Modernising infrastructure for DRM

There is a need to increase the accessibility and uptake of technology to support DRM, especially when it comes to information gathering, hazard and vulnerability assessment, early warning, coordination and response capacity. For example, guaranteeing mobile devices (tablets and smart phones) for field workers, integrated GIS mapping tools for inhouse professionals, disaster management databases and crisis management software should be among the standard tools available in every national DRM agency (Williams, R. and Phillips, A, 2014).

Satellite data can be costly and difficult to obtain, but countries can make use of available international agreements, such as "The International Charter – Space and Major Disasters",[55] which provides cost free space-based data and information to support response efforts during emergencies. Although not many DRM authorities in the Caribbean are authorized users of the Charter, it has been used in many disaster events in the subregion and activated through international agencies such as the United Nations Office for Outer Space Affairs (UNOOSA) and the United Nations Institute for Training and Research/ Satellite Analysis and Applied Research (UNITAR/UNOSAT).

More than collecting data, geo-information and spatial databases are fundamental for planning processes and decision-making. Unfortunately, these databases are not promptly available for public use and not easily

[55] For more information on the Charter use and recent activations in the Caribbean subregion: https://disasterscharter.org/web/guest/about-the-charter.

shared between State entities. Establishing legislation regarding geospatial information management would be an important initial step, as it would allow the definition and distribution of responsibilities and competences for the production, management and dissemination of geo-information at different territorial levels. A Spatial Data Infrastructure (SDI) coordinated by national or regional agencies can have the potential to oversee the collection of technologies, polices and institutional arrangements that facilitate the availability of and access to spatial data, including academic institutions, NGOs and government stakeholders.

Finally, the data gathered should be actively used to guide long-term planning processes such as spatial planning, relocation of affected communities and reconstruction plans. In this regard, using pre- and post-disaster assessments methodologies is important for standardized data collection and measurement of costs overtime. Standardized methods would allow for the production of vulnerability indexes to compare disaster related costs and effectiveness of measures at national and regional levels.

Application of ICT at community and local levels

The incorporation of inputs from vulnerable and minority groups into development planning processes allows for a more specific determination of their exposure and capacity to withstand exogenous threats and must inform the preparation of national and community-based DRM strategies (Cuny 1983; Lewis 1999; Wisner et al 2004). This includes contextual approaches such as hazard and risk assessments, in addition to vulnerability and capacity, resilience, and sustainability assessments and provision of strategic guidance for programme implementation.

Moreover, making the best use of available ICT and social media, requires the preparation and adoption of specific legislation on personal data sharing and guidelines to protect privacy while still encouraging the usage and development of DRM technologies. Succeeding at this challenge requires bringing together expertise in data science, ethics, law, risk management, communications, community participation and public policy. Standards and guidelines are expected to not only encourage companies to share data, considering that their interest will be protected, but also to increase acceptance of sharing of private information by the public and improving the citizens data security (Poljanšek et al., 2017).

Finally, another important aspect is to expand technology literacy and access to the web and mobile phone, especially among the most vulnerable populations. This approach needs to consider local capacities and cultural aspects in order to optimize crisis communication objectives. Still, traditional systems such as radios and siren systems remain important as people are more responsive to early warning alarms if they are transmitted by different means.

Mainstreaming of DRM policies and strategies into national planning

A high level of public debt and overall lack of available financial resources often prevents countries of the Caribbean subregion from making the necessary investment in DRM. It is, therefore, desirable that countries aim to improve the following aspects: a) design and implementation of policies for financial protection to the risk of disasters; b) estimation of the annual resource needs to cover the response, rehabilitation and reconstruction processes for different types of events; c) public-sector budget allocations for DRM activities, including aspects such as ICT for DRM; d) establishment of a structure for the retention and transfer of disaster risk in the country; and e) enhanced capacities in statistics and technical capacities to incorporate DRM into public investment projects (ECLAC, 2019b).

Funding ex-post measures can create significant budgetary pressures on Caribbean governments and diverts limited resources from other pressing development issues. Management of risk should be ex-ante and included in the national planning and budgetary processes. Through ex-ante approaches, shock-responsive social protection systems can be strengthened so that they are better prepared when shocks materialise. Ex-ante and ex-post disaster financing can also be enhanced through the design and application of different financial instruments such as sovereign and individual insurance, debt swaps and bonds.

Developing a subregional strategy and engagement with the international community

CDEMA as a subregional intergovernmental body is an acknowledgement to the fact that intra-regional cooperation, as well as support from international partners, is necessary to providing the environment and incentives as well as in developing the knowledge, capacities and motivation needed to build a resilient subregional DRM sector. Considering the economies of scale and other challenges for each individual Caribbean SIDS to develop its own technological space and infrastructure for DRM, and the advantages of information and expertise sharing, advancing a regional approach in DRM and TI is an imperative. Another aspect is to seek support through south-south, north-south and SIDS-SIDS cooperation and from the international developmental patterns thereby , broadening the knowledge of existing technological options worldwide and guaranteeing that local disaster agencies are connected to the global knowledge network to seek and provide advice and expertise.

The engagement of local governments having direct and localised access to information of on-going projects and success stories are a valuable source of information. This also will support the vertical and horizonal coordination with other governmental counterparts thereby promoting on-going monitoring and evaluation of projects and activities. An accessible subregional repository, hosted by one of the subregional organizations, featuring information on how technologies are being applied for disaster management and what innovative approaches have been successfully applied in the subregion would raise awareness and understanding. Moreover, partnerships with the private sector and academia across the Caribbean will be critical for understanding and applying digital and other types of technologies for disaster prediction, detection, response and relief. Networking and collaboration between the DRM communities, private sector and academia across the subregion should also be strengthened.

Eco-infrastructures adaptation in reconstruction and long-term planning

Spatial development strategies and reconstruction plans of affected areas must consider ecosystem-based approaches, green and blue infrastructures as valid and feasible options to reduce vulnerability to hazards. In this sense, it would be relevant to explore public-private partnerships and take advantage of the extensive experience that some countries have with this type of nature-based solutions, traditional construction techniques and available technology.

Applied research and use of geospatial technologies including for example GIS and remote sensing equipment can be applied to better understand interaction between physical and eco-systemic processes. Risk-informed land use planning can be used to guide relocation of essential infrastructure if necessary and to reduce exposure. It can also be a guiding principle to expand and support protected areas including mangroves, coastal areas, wetlands and forest reserves. Based on these assessments and wherever possible, incentives, such as regularization of land tenure and compensations, must be used to encourage resettlement in safe areas.

Final remarks

Technological applications are a product and an enabler of a calculated and science-oriented approach to infrastructural planning, collecting and managing data, forecasting, monitoring and, engaging communities in DRM, funding and supporting long-term resilience. Continued developments in this field are necessary for supporting increased understanding of hazards, exposure, vulnerabilities and resilience rebuilding.

In the Caribbean subregion, notwithstanding the challenges in data management, limitations in funding DRM initiatives, technical expertise and connection between the scientific community, DRM experts and end-users, there continues to be considerable achievements in innovation and technological development. Successes in research, science, innovation and the application of technologies in all pillars of DRM should serve as a basis for further progress nationally and subregionally. The paper identified selected initiatives in this field and recommends the continued monitoring, documentation, information exchange and initiatives within the Caribbean subregion.

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