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Navigating Flood Resilience: Challenges, Solutions, and Lessons Learnt from the Dominican Republic

Hamlet David Reynoso Vanderhorst *, Chaminda Pathirage and David Proverbs

Faculty of Science and Engineering, School of Architecture and Built Environment, University of Wolverhampton, Wolverhampton WV1 1LY, UK; c.pathirage@wlv.ac.uk (C.P.); david.proverbs@wlv.ac.uk (D.P.)
* Correspondence: h.d.reynosovanderhorst@wlv.ac.uk

Abstract: Recent unprecedented events worldwide, such as floods in Dubai, recurring heavy rainfall in Santo Domingo, and abrupt temperature changes in the United Kingdom (UK), underscore the tangible impacts of climate change. In response to escalating threats from natural disasters, global communities prioritise resilience and effective disaster management systems. This paper addresses best practices for managing abnormal floods, laying the foundation for the next generation of preparedness and mitigation plans. Focusing on flood risk in Santo Domingo, the study employs the Community Disaster Resilience Framework, conducting a workshop with over 100 stakeholders from government, private, and academic sectors. The assessment spans physical, economic, environmental, and social aspects, revealing common challenges in infrastructure upkeep, public awareness, urban planning, drainage, and economic disparities. The paper proposes technological solutions like predictive maintenance and smart drainage systems, emphasising the potential for implementation. Recognising the importance of community involvement and preparedness, insights from the United Kingdom guide initial steps in strategy development. The conclusions advocate for collaborative efforts among government, academia, and society to navigate the complexities of disaster management and community resilience, ultimately proposing a framework to address these challenges. Further research is suggested in expanding online platforms for disaster risk reduction education in the Caribbean region.

Keywords: flood resilience; heavy rainfall; disaster risk management framework; workshop; knowledge exchange

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1. Introduction

Floods in any populated part of the world can cause severe damages to assets and human lives. The economic consequences of floods significantly alter the flow of emerging or stable economies. In recent years, the issue of climate change has escalated to a critical global concern. For example, in the month of November 2023, various unprecedented events occurred worldwide, such as the 17 November flooding in Dubai [1], 18 November new record of more than 400 mm of rainfall in 24 h in Santo Domingo [2], and others in Africa [3]. These recent events, not only have disrupted local ecosystems, but also had far-reaching implications for international relations and geopolitics.

Consequently, universities and governments worldwide have been reassessing their priorities by including flood risk management in their agendas. Internationally recognized frameworks, meetings, and agreements, such as the United Nations Climate Change Conference (COP) 26,27,28, the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), the Escazú agreement (2018) for Latin American and Caribbean Countries, and sustainable development goals (SDGs), have been taken as key guidelines for nations across the globe. But, unprecedented events require unprecedented actions and frameworks to cope with their particular settings. For example, the current investments involved in disaster risk management (DRM) have increased drastically due to the rising number of

climate-related disasters. There are some frameworks that have been used to understand in-depth the win–win situations of proactively addressing challenges in any disaster management setting—in this case flood management—that can significantly improve the social, economic, environmental, and physical wellness of the citizens.

A recent study across 12 countries, including Mexico, El Salvador, Nicaragua, Peru, Montenegro, Bangladesh, Nepal, the Philippines, the United Kingdom, Afghanistan, Nepal, Vietnam, and Indonesia, proposed a framework to capture the broader benefits of DRM beyond just damage reduction that incorporates intangible assets. The term is called "multiple resilience dividends", which encompasses social, economic, and environmental advantages that contribute to sustainable development by reframing disaster resilience as recovery, growth, and improvement [4]. The idea reflects that creating jobs through infrastructure development and maintenance improves health and well-being by reducing environmental hazards, strengthening infrastructure for better climate resilience, improving capacity building and international network generation, and boosting local economies through increased safety and tourism as the positive long-term outcomes in investing disaster risk management, especially for flooding.

From an academic perspective, an example of a resilience dividend of a network group is seen in a study published in 2023. It presents that, since 2016, some Peruvian and Latin American universities have been leading the charge in disaster risk management and climate change adaptation education. Their multidisciplinary network, fueled by discussion forums, integrates crucial knowledge into university programs [5].

Moreover, in another study, a series of training workshops between 2017–2019 by College of Science Technology and Applied Arts of Trinidad and Tobago (COSTAATT), the Department of Food Production, and The University of the West Indies, Trinidad have built regional capacity in participatory DRM across six Caribbean Small Island Developing States (Granada, Antigua and Barbuda, St. Vincent and the Grenadines, St Kitts/Nevis and Belize). Over 150 stakeholders from the water sectors participated, contributing information on hydro-climatic hazards and potential mitigation measures. Evaluations at training completion after 6 months showed significant knowledge transfer and institutional/policy impacts. High participant satisfaction (99%) and application of knowledge to work (85%) were reported [6].

Therefore, these efforts highlight the feasibility and significance of "resilience dividends" or cross-sectoral collaboration in tackling complex environmental challenges, even transcending the traditional "developed" vs. "developing" nation contexts. The current rapid pace of environmental change poses a fundamental challenge for all species, necessitating swift adaptation strategies. Integrating this accelerating rate of change into survival strategies is crucial for building resilience and securing future viability. Unfortunately, not all the countries are aware of or present scientific evidence of their advancements and needs as the Dominican Republic. The knowledge gap in the country for centralised and scientific information has limited a long-lasting coping capability of the cascading effects of natural flooding events. Therefore, an in-depth investigation has been suggested.

2. Context

After the participation of the Embassy of the Dominican Republic with the United Kingdom and Northern Ireland at COP26 and 27, the agenda in terms of climate change was scheduled to disambiguate the situation in the Dominican Republic. The embassy commission was visiting the University of Wolverhampton for academic purposes and the discussion about climate change with the pro-vice chancellor and other academics was evidently on the table. The ambassador, along with their commission, expressed their concern regarding the flood events at the Distrito National, Santo Domingo, Dominican Republic and the lives and million-asset losses perceived. Therefore, the team of experts at the University of Wolverhampton, along with local universities (Universidad Iberoamericana (UNIBE) was the host) developed a workshop to bridge the gap in capacity building at academic level.

The idea of celebrating this type of community-based workshop in the Dominican Republic has been delivered previously on a technical basis but not widely spread to students, academics, and policy maker stakeholders nor with an educational perspective with the United Kingdom.

This country boasts a strong track record in flood risk reduction through various research initiatives, making it acceptable to strengthen the collaboration between academic bodies. The UK have yielded comprehensive reports identifying solutions for both domestic implementation, including its overseas territories, and informing its contribution to international agendas aimed at assisting developed and developing countries. The impact of knowledge transfer and exchange workshops are validated as effective by fostering active engagement, trust, and continuous learning, while raising public awareness and support for initiatives addressing societal needs.

Recognizing the potential challenges and limitations faced by the Dominican Republic, it was suggested that the workshop should be structured as a contrast of experiences. This approach aims to generate understanding in how the flood resilience process should be adequately managed. While traditional flood risk assessments, in the Dominican Republic, often focus solely on communities near rivers, the workshop would consider broader factors like urban landscapes, environmental impact and diverse community experiences to inform a more comprehensive and effective approach to flood resilience. The recent deluge on 3-h 250 mm rainfall on the 4 November 2022 demonstrated that even seemingly safe areas are not immune to extreme rainfall events. This underscores the need for proactive approaches that address the vulnerabilities of all communities. Furthermore, where resource limitations and data gaps are common, community-based initiatives can offer valuable tools for overcoming these barriers and building resilience.

3. Flood Risk Management in the United Kingdom

The United Kingdom has a long history in managing floods. Since 1985, researchers have been investigating methodologies to predict the frequency of flood occurrence in the region [7]. As the overseas territories of the United Kingdom has faced many events recorded since 1998, the country has generated different approaches towards manage risk reduction. However, the most extensive report which captured the attention of policy makers was published in 2007, generating the *Pitt Review 2008* [8]. This report provided significant actions and recommendations to policy makers that it was inevitable to address flooding in all the United Kingdom. Furthermore, continuous major flood events occurred years later, adding efforts in creating Flood & Water Management Act 2010 and National FCRM Strategy 2011 [9]. The most recent and ambitious strategy is the National Flood and Coastal Erosion Risk Management (FCERM) Strategy 2021, which reflects innovative ways and sustainable paths to convey sophisticated solutions to address resilience after floods [10].

The track record of policies was also accompanied by the development of technical and scientific solutions. The application of deep learning and other algorithms has been a job for more recent studies, but it is still a project under discussion for determining the amount of precipitation when it is uncertain [11]. Nevertheless, researchers have tackled the flood problem from angles of capacity of response [12], degree of awareness of the issue [13], environmental dimension of social inequality [14], and others. The current topic of discussion concerns the accuracy of the hydrological models [15], their monitoring systems of critical infrastructure (bridges) [16], diversification of the frameworks [17], methods of risk evaluation in urban areas, repercussions of floods in gentrification [18], influence in the use of electric vehicles [19], and sustainable approaches to manage floods with SuDS or Sustainable Drainage Systems [20,21]. However, the problem of predicting the precipitation and the cascading effects is still a topic of research. Furthermore, angles from changing cloud seeding or taking conscious actions towards precipitation may be a topic for further discussion. Moreover, the nation is interpreting the concept of resilience from a mitigation and social aspect as, in other countries, deficiencies in physical, economic,

environmental, and social aspects might unleash a Pandora's Box or a hornet's nest (as could be the case in the Dominican Republic).

Finally, insights from the United Kingdom are incorporated, showcasing best practices that have proven effective in managing flood risks and enhancing community resilience associated with policies and practices [22]. These practices, grounded in the aftermath of significant flooding events, offer valuable lessons and potential avenues for adaptation in the Dominican context. A framework is developed to provide guidance on how to adequately address uncommon flooding events.

4. Flood Risk Management in the Dominican Republic

Over the past five decades, the Dominican Republic has grappled with the mounting challenge of floods. Some studies conducted before 2009 used to refer to floods as a source of energy generation from dams since 1979, e.g., Nizao River [23,24] and Hoya Enriquillo [25]. The 2004 hurricane's cascading effects, however, redefined this perception. Flooding of the transboundary river Soliette killed 1000 people in Haiti and 400 in the Dominican Republic, destroyed towns, and left behind devastation and destitution [26].

Later, the investigations around floods were focused on social, infrastructure, technology, environmental and management systems covering the following topics in: (1) understanding the behavior of floodings and assess flood control options during Huracan seasons [27]; (2) formulating and improving affordable flood risk mitigation plans with structural and non-structural measures [28,29]; (3) developing comparative analysis between Caribbean countries storm impact and their disaster management strategic results [30]; (4) evaluation of tsunami scenarios [31]; (5) assessing of the spatiotemporal variations of climate projections [32]; (6) briefly describing the success and challenges in school safety and disaster risk education in the South America and the Caribbean [33]; (7) applying algorithms for forecasting precipitations [34–36]; and finally, (8) revaluating of the educational infrastructures against disasters and plans for relocation of vulnerable settlement into a free flood area (far a way of the river edges) [37]. While a few studies in relation to the Dominican Republic have sought to adequately frame and implement disaster mitigation strategies for extreme events, their focus on isolated occurrences overlook the potential for concurrent intensified phenomena. Such single-event frameworks fail to account for situations where multiple events overlap, effectively doubling their collective impact. Recognizing this limitation, it has necessitated a shift towards holistic navigation of risk contexts, encompassing the dynamic interplay of concurrent hazards and fostering resilient communities prepared for complex disaster scenarios, seeing the investments as part of the resilience dividend for wellness.

Hence, the unique context of Santo Domingo, marked by abnormal rainfall, amplifies existing challenges in infrastructure maintenance and availability, education shortcomings, urban planning deficits, and environmental conservation. These become not only pressing needs but also a hub for innovative solutions and international academic collaboration in the pursuit of global solutions.

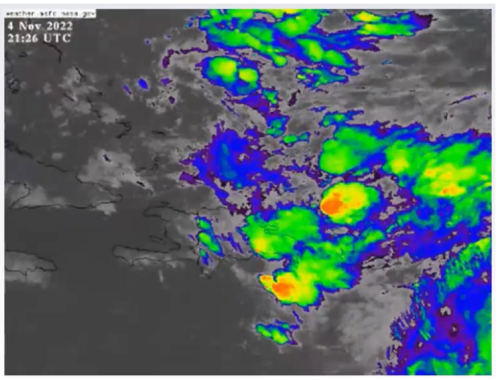
Therefore, the aim of this paper is to delve into a comprehensive examination of resilience and effective disaster flood risk management within the context of Santo Domingo city, the Dominican Republic. It analyzes challenges faced and proposes solutions to bolster disaster resilience, particularly against floods, with the lessons learned from this context.

5. Research Methodology

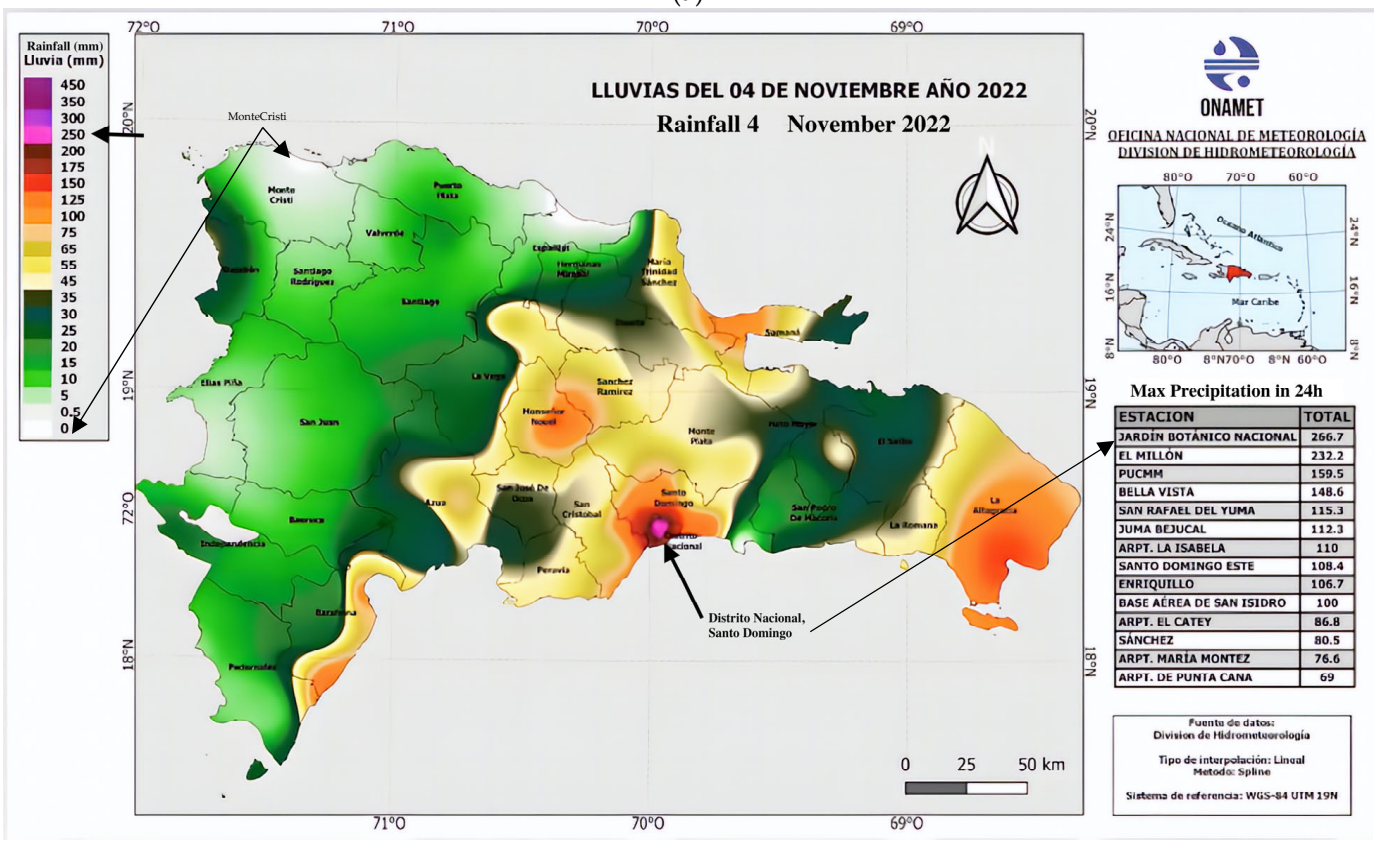
5.1. Abnormal Rainfall Event of 4 November 2022

Yearly, the country suffers hurricane warnings and rainfalls that alert and hinder the local market [38]. The recurring devastation caused by hurricanes in the Dominican Republic has been an issue for the private, public, and international agencies to address effectively. The country has suffered since the pandemic various events that have influenced direct and indirect the economic stability. The most recent flood was on 4 November 2022, at the capital city of Santo Domingo caused by an unprecedented and unpredicted abnormal

rainfall event that culminated in complex meteorological factors, characterised by the convergence of a tropical wave and the presence of an upper-level trough, known as a "vaguada." These atmospheric conditions resulted in a heightened state of instability, ultimately leading to the development of mesoscale convective systems (Figure 1a,b). The Initial meteorological models had predicted comparatively lower levels of rainfall in the Gran Santo Domingo province. However, the actual event defied these expectations, delivering torrential rainfall that surpassed the region's monthly average for November in a mere three hours.



(**a**)



(**b**)

Figure 1. Satellites Images and Map of Raining. (**a**) Satellites image of the Raining Clouds over the Dominican Republic on 4 November 2022. (**b**) Rainfall map data on the 4 November in mm. Pink fuchsia shows the highest concentration of rainfall (250 mm of rainfall) in the Distrito National, Santo Domingo and in white the lowest one at Monte Cristi (0 mm). The map is in Spanish.

The consequences were severe urban flooding, which inflicted significant losses of lives and property damage (Figure 2), such as 8 deaths, 610 reported insured drowned automotive equipment, and infrastructure and house damages equivalent to US$100 million to residences of the city [39]. This event serves as a stark reminder of the escalating frequency of heavy and sudden rainfall events, a phenomenon partially attributed to shifting climatic patterns. The cause of this event was arguably discussed between the news and government institutions, but scientific conjectures were not possible to attain due to the lack of evidence and the complex levels of variables involved within the problem. Some of the conjectures gathered from the news reflected the following:

- The city was unable to cope with flooding issues as the current drainage capability was not available (only 18% of the waste drainage was installed in the city and this % was also used for pluvial waste).
- Another hypothesis related to sewers clogged by solid waste on the streets.
- There was not an early warning alert regarding the magnitude of the event (causing loss of life).
- People were not psychologically prepared to face this type of challenge, causing severe commercial issues.
- The city was not adequately designed for the current vertical growth as the underground infrastructure could not handle the demand.

(**a**) (**b**) (**c**) (**d**)

Figure 2. Flooded cars, traffic, and parking areas. (**a**) The flooded ground floor of a dealership. (**b**) Extensive ground flooding, covering three-fourths of the area. (**c**) Inundation at a traffic underpass during congestion, with drivers attempting to leave the water. (**d**) Slightly flooded underground parking area.

5.2. Workshop Foundations

Based on these conjectures, the workshop was divided into key presentations, share experiences using community resilience framework and site visits.

The foundation of this discussion of floods is rooted in understanding the challenges, solutions and lessons learnt from the case of Distrito Nacional, Santo Domingo in order to discern which are the adequate resilience dividend to look at. Previous studies, investigates this type of questions utilising a workshop, team of academic along with policy makers and practitioners to apportion a recommendable course of action for abnormal events (Table 1). This approach assures the quality of the participants.

The workshop was structured in a two-day event. The first day was focused on policy makers, government knowledge exchange, practical and academic practices. The second day was focused on student focus and academic exchange. On this day, an excursion to a construction site of a prone-zone in the Distrito Nacional, Santo Domingo, was made [37]. The area site visit was to the area of Santo Domingo Savio.

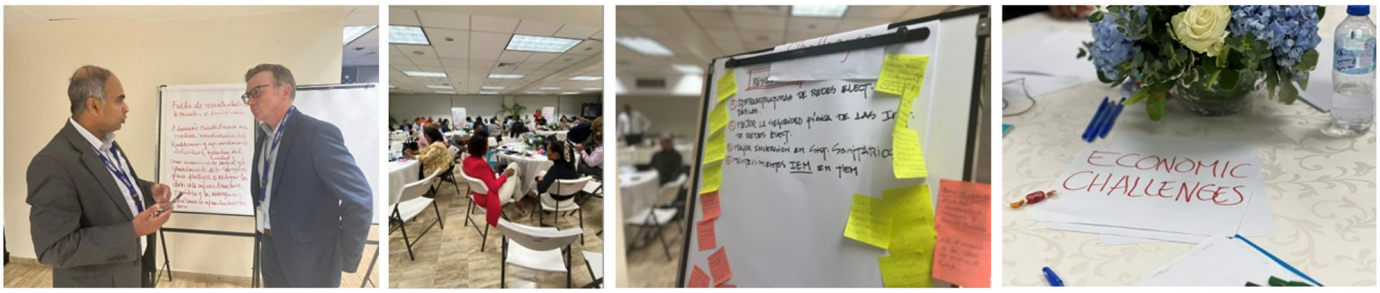
On the first day, more than 100 participants attended, and the interactions between the government representatives, students, and academia were recorded online. To gather suitable data, specific segregations of participants were made as follows: 9 participants

from the private sector, 35 from the public sector, 20 from academia, and 37 students. Furthermore, additional government entities decided to contribute with additional experiences and perspectives during the workshop sessions. Lastly, as the framework of resilience dividend was appropriate for presenting feasible long-term solutions, another framework was used to articulate the priorities of the city to be addressed. The framework applied was the community disaster resilience framework, comprising sixteen distinct domains or clusters, assessing a community's capacity to anticipate, prepare for, respond to, recover from, and adapt to the adverse impacts of disasters and shocks (Figure 3). These domains encompass various facets of human life, from physical infrastructure to social well-being, reflecting the multifaceted nature of resilience [40].

Table 1. Sessions and profiles of speakers, day 1.

Session Title	Profile
Welcome and Introduction to the Workshop (Inauguration Act)	Chancellor of UNIBE
	Ambassador for the Dominican Republic in the UK
	Ambassador for the UK in the Dominican Republic
	Ministry of Higher Education, Science and Technology
	President of the PROPAGAS Foundation
Keynote—Dominican Republic (DR) Flood Resilience Situation	City Council of Distrito National, Santo Domingo
Keynote—Mainstreaming the Uptake of Low-Cost Flood Resilience Measures in UK Homes: Lessons for Dominican Republic	Dean of Faculty of Science and Engineering, University of Wolverhampton
Roundtable Discussion: Policy and Institutional Frameworks for Flood Resilience	Director of Planning, Free Trade Zone from the Ministry of Economic, Planning, and Development
	Deputy Minister of Environmental Management from the Ministry of Environment and Natural Resources
	Adjunct Lecturer at the University of Illinois at Urbana-Champaign, USA
	Executive Vice President of the National Council for Climate Change and Clean Development Mechanism
Community Disaster Resilience: Key Vulnerabilities	Associate Head of School-Research and Professor of Brownfield Research and Innovation, University of Wolverhampton
Building Flood Response Capacities in the Dominican Republic	Deputy Director and Head of the Division from Emergency Operations Centre (COE)
Disaster Management for Flooding and Resilience of Distrito Nacional, Santo Domingo in the Face of Climate Change Effects	Lecturer and Researcher at UNIBE
Flood risk mitigation from the UK perspective	Principal Lecturer and Head of the Civil Engineering Department University of Wolverhampton

During the 2nd day of the workshop, a reduced group of students and academics were involved in the site visit, where it explained the process of improving informal settlements at the edge of the river to a high-quality safe property at an adequate distance for the mass of water. The action of moving people into a free safe property is an arduous and challenging job that cases were shared along with the site map to elaborate on the strategies and further actions to dignify citizens and recover the edges of the River Ozama.



(**a**) (**b**) (**c**) (**d**)

Figure 3. Workshop challenge presentations. (**a**) Discussions about the challenges, (**b**) participations and contributions to the challenges, (**c**) post-it notes made during the workshop, (**d**) economic challenges involved.

At the end of the 2-day workshop, the team of academics started to analyze and refine the data gathered from participants and additional contributions from other government institutions. More than 64 ideas regarding flood mitigation and resilience in Spanish and English languages were developed, as well as data of annual precipitations. Furthermore, the ideas were processed utilizing ChatGPT 3.5 by prompting the following workflow:

1. Translation of the original text: the initial text provided in Spanish was translated into English to make it understandable for English-speaking readers.
2. Text segmentation: the translated text was divided into different sections to analyze and summarize each part separately.
3. Section analysis: Each section was analyzed to extract key information related to the challenges and solutions for flood disaster resilience. This involved identifying challenges and solutions, and their categorization based on social, physical, environmental, and economic aspects.
4. Compilation and organization: The identified challenges and solutions were compiled and organized into a table format. The table included categories, specific challenges, and corresponding solutions.
5. Formatting the table: the table was structured to provide a clear and concise overview of the challenges and solutions, making it easier to read and understand.

Finally, a discussion regarding the challenges, solutions, and lessons learned from these cases took place.

6. Results

Common Challenges in Santo Domingo

In Distrito Nacional, Santo Domingo and similar cities, challenges in terms of disaster management and flood resilience are diverse. The event on 4 November was notable for receiving over 250 mm of rain in a 3-h period, caused by the manifestation of two continuous atmospheric phenomena. Typically, this amount of water would be manageable for the city, but the period of time was too short to fully cope and avoid inundations.

As revised with the data provided by National Office of Meteorology and Hydrology (ONAMET), the Santo Domingo was hit with higher amount of precipitation in previous years. 2011, 2008, and 2016 have been the years with high amounts of rainfall but the problem seen in 2022 and recently 2023 presumes that the issue is about related to the time capacity of response against the event of the city as seen in Figure 4. The city may only manage a certain amount of rainfall during a certain period of time; this must be improved, the abortion capacity, by utilizing different methods.

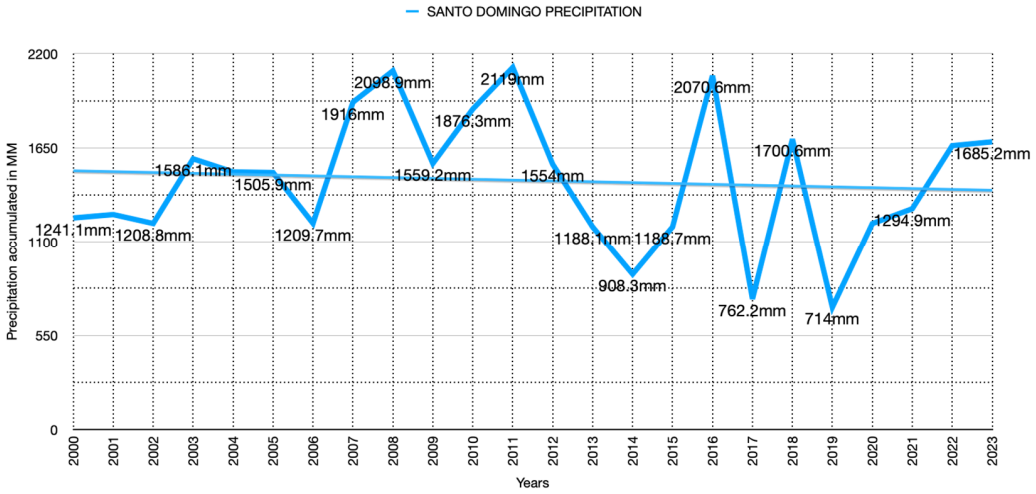


Figure 4. Graph of annual precipitation accumulated in MM between 2000–2023 of the cities of Santo Domingo.

Furthermore, the participants were in groups and discussed the challenges concerning the natural event. There were many insights into flood cases that have happened in rural areas. These scenarios were analyzed and linked with the case of the urban providence of Santo Domingo. The challenges and solutions presented in the providence of Santo Domingo regarding flood risks mentioned during the workshop are detailed in Table 2 below:

Table 2. Categories, Challenges and Solutions proposed.

Category	Challenges	Solutions
Social Challenges	Lack of information on risks and vulnerabilities	- Establish a centralized information center with hydrometeorological and risk data. - Create training and awareness programs for communities about flood risks.
	Lack of reliable and aligned agendas between public institutions	- Establish mechanisms for citizen participation in decision making related to risk management. - Create transparent and accessible communication channels for the community. - Implement awareness campaigns on the importance of cooperation with institutions.
	Lack of social support during floods	- Establish a specific shelter and support center in disaster situations. - Create community support networks and provide training in emergency response skills. - Promote solidarity and active participation in evacuation and preparedness plans.
Physical Challenges	Weak electrical infrastructure	- Invest in improving and strengthening electrical infrastructure to withstand extreme weather events. - Implement renewable energy and backup systems to ensure supply during disasters. - Establish specific action plans for post-flood electrical recovery.
	Location of vital infrastructure in vulnerable areas	- Conduct detailed risk analysis and vulnerability assessments before locating critical infrastructure. - Adapt land-use planning to climate change threats, ensuring secure locations for critical infrastructure. - Implement evacuation and contingency protocols for these areas.
	Obsolete and poorly connected sewage system	- Increase city permeability by implementing sustainable stormwater management technologies. - Invest in the modernization and expansion of the sewage and sanitation system. - Promote the adoption of decentralized collection and treatment systems.

Table 2. *Cont.*

Category	Challenges	Solutions
Environmental Challenges	Indiscriminate extraction of alluvial materials	- Establish clear regulations and limits for the extraction of alluvial and granular materials in areas near rivers and tributaries. - Promote sustainable extraction practices and ecological restoration in affected areas. - Encourage collaboration between communities and companies for responsible natural resource management.
	Topographic changes due to urban growth	- Implement building codes that consider topographic changes and the potential creation of flood zones. - Develop monitoring systems for topographic changes and geological risks. - Establish urban growth management plans that minimize environmental impacts.
Economic Challenges	Concentration of wealth in threat-prone areas	- Promote economic diversification in vulnerable areas, creating employment and development opportunities. - Promote investment in climate-resilient sectors. - Implement financial inclusion policies for at-risk communities.
	About 40% of the country's population occupies flood-prone areas	- Develop housing programs and land planning that address the needs of the population and reduce informal settlements. - Implement accessible financing mechanisms for the acquisition of safe housing. - Regularize informal settlements comprehensively and sustainably.
	Investment in hydrometeorological data and centralized availability	- Invest in data collection systems for hydrometeorological data and centralize them on accessible platforms. - Facilitate public access to updated data for informed decision making. - Use data to improve forecasting and early warning models.
	Implementation of climate-adapted land-use planning	- Integrate climate change into land-use planning, considering flood-prone and risk zones. - Establish resilient construction standards and land-use regulations to minimize impacts. - Facilitate adaptation and relocation of infrastructure based on risk.
	Implementation of codes ensuring urban drainage	- Establish building codes that require efficient and flood-resistant drainage systems. - Promote investment in drainage infrastructure and stormwater management. - Train construction professionals in the application of drainage codes.

7. Discussion

During a recent workshop, participants highlighted several communication gaps and resource limitations that hinder effective social preparation for disaster events in the region. A key concern was the lack of comprehensive disaster management education for citizens. Within this realm, ensuring the reliability and consistency of information disseminated to the public emerged as a critical issue. Establishing a centralised information body, accessible for both top-down and bottom-up communication, was considered crucial to address discrepancies and promote understanding. Furthermore, raising awareness about proper prevention practices in environmental sanitation and building resilience strategies was identified as a means to enhance community preparedness, raise intellectual capacity, and ultimately, reap the collective benefits of resilience dividends. Solutions towards a digital approach to delivering immersive experience learning should be adequately contemplated by fomenting innovation and start-ups to participate.

Furthermore, the group involved in physical challenge mentioned the status of the facility management sector in the city. Participants identified the city's weak electrical power supply system as a major concern, highlighting the need for reliable and resilient energy support for emergency response. Additionally, the proximity of critical infrastructure, such as schools and hospitals, to hazardous areas was deemed unacceptable. Furthermore, the infrastructure's drainage capacity was recommended to be improved by utilizing sophisticated approaches or to expand the current capabilities near to critical areas (hospitals, schools, etc.). Also, maintaining a consistent monitoring of the infrastructure was a solution to the electricity issues. Moreover, calls were made for improved land-use

planning that incorporates climate change resilience and integrates evacuation protocols within communities. Specific suggestions included upgrading underground electrical distribution systems and implementing double-check procedures for the placement of critical infrastructure to minimise risk to vulnerable populations within the urban fabric.

Moreover, the environmental challenges mentioned by the participants reframed the challenge as a lack of regulatory codes or penalties for unauthorized use of natural resources and irregularities in considering the topographic attributes of cities. Concerns regarding this were addressed, looking into policies that award good practices of sustainability facing wetlands, rivers, and brownfields.

Lastly, the economic challenges shown by the participants referred to the lack of evaluation of the resilience dividends towards investing in climate-change infrastructures and incentives to build or develop technological solutions in a direction sustainable for climate change. While the site visit observations suggested prioritizing awareness of building over immediate infrastructure investment, acknowledging the need for eventual infrastructural development remains crucial despite potential delays. Among flood victims, individuals with a limited educational background might require additional support to grasp the concept of alternative non-slum living arrangements. For this specific group, temporary infrastructure solutions could serve as a bridge until further actions focused on their safe relocation are implemented. Conversely, for victims with higher education levels, immediate infrastructure improvements might be prioritized due to the prohibitive cost of land in their current locations. Additionally, considering the infrequent nature of floods in these areas, alternative safeguarding measures, such as insurance policies, enhanced building codes, and construction practices, could be implemented instead of relocation.

7.1. Lessons Learned from Dominican Republic Santo Domingo

Despite the citizens seeming to be unaware of the implications of the unknown probability of the amount of rainfall in the Distrito Nacional, Santo Domingo, they require an immersive education regarding short rainfall events and their consequences in urban areas.

The Santo Domingo floods of 2022 highlighted the importance of urban planning, citizen engagement, and collaboration in building resilience to extreme weather events. Urban planning plays a critical role in reducing flood risk by designing resilient infrastructure, zoning areas appropriately, and considering climate factors in urban development. Resilient infrastructure is designed to withstand and recover from flood damage. This includes things like elevating buildings and roads, using flood-resistant materials, and creating floodplains to absorb excess water. Proper zoning can be used to reduce the flood risk by directing development away from flood-prone areas. Climate-conscious urban development means considering climate factors when planning urban development, as seen in the literature review [37]. This is important because climate change is increasing the frequency and intensity of floodings events.

Citizens also play a vital role in disaster management and resilience. Public awareness, personal preparedness, and the adoption of prevention practices are essential. Citizens need to be aware of the risks they face and how to stay safe during a flood. Public awareness campaigns can educate people about the signs of a flood, what to do in the event of a flood, and how to reduce their risk of flood damage. Citizens can prepare for floods by developing a family emergency plan, creating a flood kit, and knowing their evacuation route. Citizens can also help to reduce flood risk by adopting prevention practices, such as clearing gutters and downspouts, installing flood barriers, and elevating their homes and businesses. Citizens can also collaborate to reduce flood risk and manage flood events. For example, they can report risk situations, participate in drills, and follow authorities' instructions during extreme events.

Collaboration among government authorities, academia, and society is essential for risk management and resilience. Academia can provide research and training on flood risk management. Researchers can develop new technologies and strategies to reduce flood risk and improve flood resilience. Government authorities can implement policies and

prevention measures to reduce flood risk. This can include things like zoning, building codes, and flood early warning systems. Society can actively participate in flood risk management and resilience by contributing local knowledge and expertise. Communities can also develop their own resilience plans and initiatives, as carried out in the UK [10]. The UK has a long history of dealing with floods and has developed a number of best practices that could be applicable in the Dominican Republic. These include advanced early warning systems, citizen participation in urban planning, and resilient drainage infrastructure.

7.2. Technology and Innovation in Disaster Management

Innovation is vital to address traditional challenges from angles never seen before. The challenges that the Dominican Republic face have a pertinent position to address as a developing country. Some of the past events have presented weaknesses in aspects of technological advances or lack of real-time data for accurate decision-making processes. Some of the participants informed that the sophistication and extension of methods of data collections can drastically provide more accurate weather forecasts. Some of the innovations intended to be used or improved are mentioned Table 3 below.

Table 3. Ideas Ideas and technological solutions for mitigating Floods.

No.	Ideas	Description
1	Predictive Maintenance	Use technologies like IoT sensors and data analysis to predict and prevent failures in electrical and drainage infrastructure.
2	Education and Community Engagement	Develop mobile applications and online platforms to educate and promote community participation in disaster management.
3	Sustainable Construction Technology	Promote construction techniques and materials that are water-resistant and adaptable to different climates.
4	Smart Drainage Systems	Implement smart stormwater drainage systems that adjust gates and drains in real-time.
5	Waste Collection and Management Systems	Introduce technological solutions for solid waste management, such as smart containers with fill-level sensors.
6	Green Infrastructure	Create urban spaces with green infrastructure, including green roofs and walls, functional floodable parks, and permeable areas.
7	Geographic Information Systems (GIS)	Use GIS technology to identify high-risk areas and plan land use more effectively.
8	Focus on Renewable Energy	Promote the generation and storage of renewable energy to strengthen electrical grids during climate events.
9	Early Warning Systems	Develop advanced early warning systems based on meteorological forecasts and AI models to predict floods accurately.
10	Blockchain Technology for Tracking and Regulation	Implement blockchain technology to track compliance with regulations in infrastructure construction and management.
11	Nature-Based Approaches	Restore and preserve natural ecosystems like mangroves and wetlands that act as flood barriers and absorb excess water. Design multiform drainage structures for natural behavior during floods.
12	Participatory Design	Involve the community in the planning and construction of resilient infrastructure and systems by smartphone apps or incorporate flooding sensors to alert citizens in specific areas.

Furthermore, undertaking an in-depth examination of the lessons from the UK, one of their greatest practices was the use of sustainable drainage systems (SuDS). They are a type of urban drainage system that is designed to mimic natural drainage processes. SuDS use features such as green roofs, rain gardens, and permeable paving to slow down the flow of rainwater and allow it to soak into the ground. This can help reduce the risk of flooding and improve water quality.

The UK has been a pioneer in the use of SuDS. In recent years, SuDS have been incorporated into the design of new developments and have been retrofitted to existing areas. This has helped to reduce the flood risk in many parts of the UK. In addition to SuDS, there are a number of other urban planning strategies and innovations that the Dominican Republic could learn from the UK. These include:

Green spaces: Green areas, including parks and gardens, may absorb precipitation and lower the danger of flooding. More green spaces should be added to cities in the Dominican Republic, especially those with a high risk of flooding.

Blue–green infrastructure: This type of infrastructure combines blue and green elements, such as ponds, marshes, and canals. When it rains heavily, blue–green infrastructure can help to store water and slow down the flow of precipitation. To lower the danger of flooding and enhance water quality, the Dominican Republic may build more environmentally friendly infrastructures in metropolitan areas.

Low-impact development (LID): LID is a form of development that is intended to have as little negative environmental impact as possible. Urban planning may use LID concepts to lower the danger of flooding. LID principles, for instance, may be utilized to limit the amount of runoff produced when designing new buildings and roadways.

Furthermore, discussing further advancements in innovative ways to address issues of search and rescue and data availability during resilience stage is the application of unmanned systems and their variations in swarm technologies. Unmanned Systems capable of generating live streaming visual 3D representations of the dynamics of the disaster area could make agile decisions in locating aids and executing effective strategies of urban regeneration. Further insights into using swarm technology of unmanned systems, artificial intelligence, and blockchain for autonomous search and rescue and data sharing with scenarios are shown in Figure 5.

Figure 5. Representations of a decentralized system of unmanned systems in the UK and the Dominican Republic, generated by Midjourney. Four different scenarios are presented where unmanned systems and swarm technology could be applied before and after floodings.

The Dominican Republic can lessen the danger of flooding in urban areas and safeguard its citizens and businesses by implementing these and other urban planning technologies and initiatives. By adopting these and other urban planning strategies and innovations, the Dominican Republic can reduce the risk of flooding in urban areas and protect its people and businesses.

8. Contribution to Knowledge: A Framework for Implementing Flood Solutions

After revising the lessons learned and the challenges and solutions proposed to the city of Santo Domingo, a framework for flood management addressed these challenges and provided insights from other countries with similar experiences, which could be adapted as baseline and the suitable parts could be replicated. For example, Puerto Rico could assess the main city areas and identify how to appropriately locate cars or invest in infrastructure to reduce the risk of flooding for assets and people. For smaller islands, drone-based mapping and digitalization of flood dynamics in potential scenarios could enhance policy design. Three-dimensional modeling of vulnerable sites could further inform code updates and promote sustainable practices. These investments would represent a resilience dividend, ultimately leading to improved construction codes and enhanced sustainability.

As a mitigation response for any natural event, the government must evaluate and reinforce any infrastructure that could put their citizens in danger. Recommendations for developing digital twin models regarding infrastructure could provide live information about the maintenance status and, furthermore, assess and identify the flood-prone areas and provide online and offline educational material for citizens. In cases when the displacement or improvement of an area's infrastructure is a challenge, identification of equipped shelters must be an option for citizens. Moreover, the development of technological solutions such as a flood app for direct communication with images, voice, and video concerning floating vehicles, dangerous behavior, or emergency rescue situations is recommended. Additionally, designated hill parking areas for vehicles during floods is a suggestion that could minimize the loss of luxury vehicles as well as locate them to an area for sheltering.

Then, regarding the preparedness stage, financial recovery sponsors, protocols, and text messages for vulnerable areas are strongly recommended. Some of these recommendations can be paired with videos or illustrations that indicate the approximate amount of precipitable water compared to previous events. For example, the forecast of heavy rain maybe be around a critical level of more than 200 mm in a short period, like the 4 November 2022 event, or a level of more than 400 mm in a short period, such as 18 November 2023. These examples provide a context for citizens, enabling them to understand technical meteorological data.

As a response to the event, the government must establish a centralized coordination mechanism with clear leaders, regarding when it is safe to declare the event is over and the steps forward for rehabilitating or reconstructing specific infrastructures. Considerations of green infrastructure, mental health assistance, and long-term education continuity are necessary for the city of Santo Domingo.

Finally, in the recovery stage, the financial sponsors, ministries, citizens who reported issues on the app, insurance companies, and educators should provide support based on their institutional nature aligned with government instruction in order to avoid duplicity of duties and responsibilities. The app should be a centralized source of data for multiple stakeholders that can provide fast and effective recovery after the event. As cultural challenges are faced when implementing certain solutions, the urgency of an effective solution will provide enough drive to act within a fast-paced system. Below Figure 6 is the framework, with the details and descriptions of the suggestions for general use. The proposed framework offers a springboard for several crucial initiatives, aligning with international best practices for disaster insurance, fostering collaboration among academic networks, bridging language barriers for knowledge exchange, establishing a regional innovation hub for disaster management, and unifying risk management platforms within the Caribbean. However, a persistent gap in general knowledge about flood risk reduction remains a challenge. For the Dominican Republic, a dedicated technological platform for disaster education is crucial to address this knowledge gap and build long-term resilience.

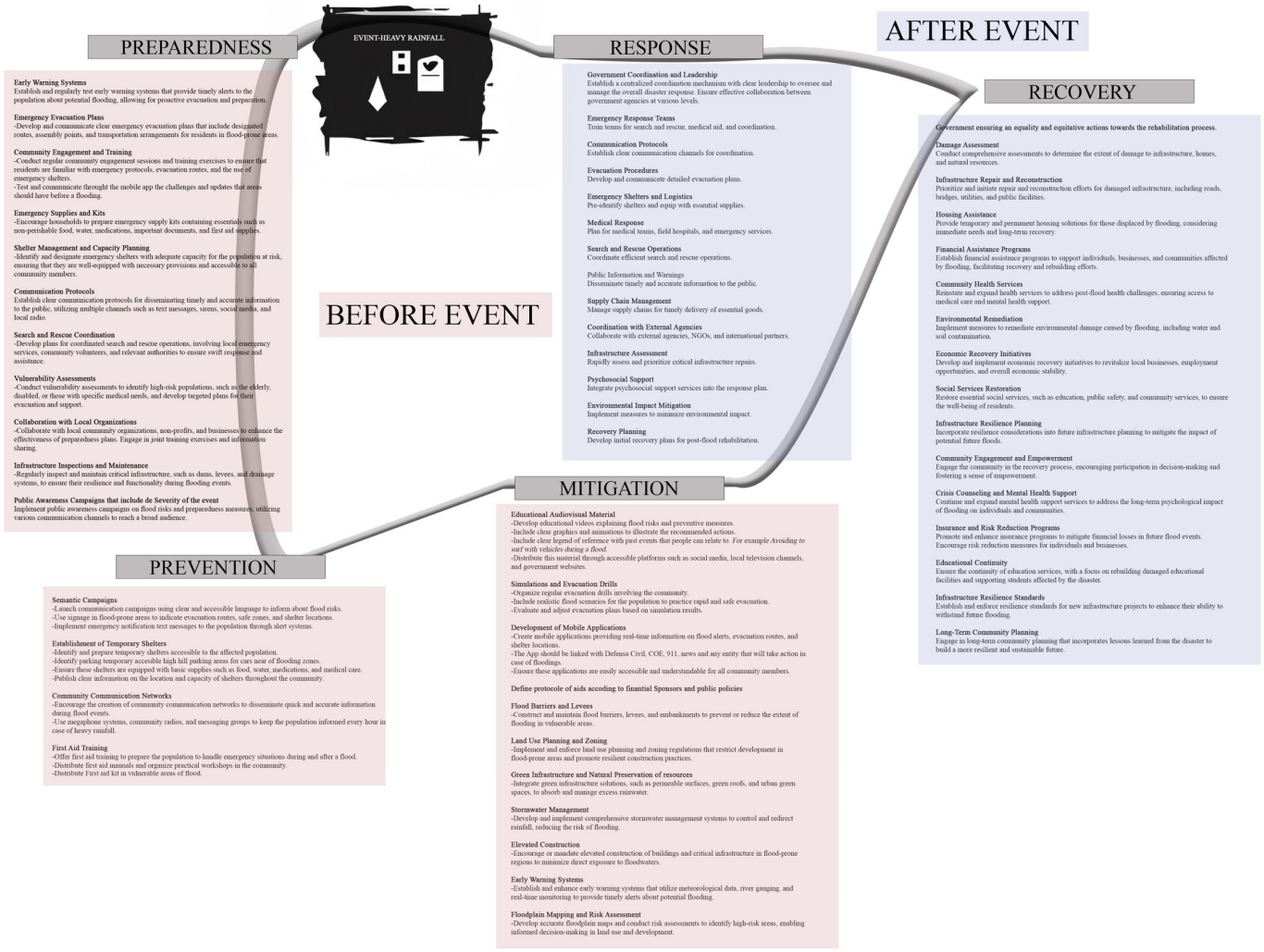


Figure 6. Framework for Flood Resilience in the Dominican Republic.

9. Conclusions

This comprehensive examination of disaster resilience and management in the Dominican Republic, focusing on the flood risk in Santo Domingo, has shed light on a multifaceted array of challenges, solutions, lessons learned, and insights drawn from global experiences. In an era overshadowed by the specter of climate change, the capacity to cultivate resilience and effectively manage disasters is not just an objective, it is an absolute necessity. The aim of this paper is to delve into a comprehensive examination of resilience and effective disaster management within the context of the Dominican Republic. It encompasses a thorough analysis of the challenges faced by communities in Santo Domingo, the nation's capital, particularly regarding flood risk management. Additionally, it explores a range of proposed solutions and strategies aimed at bolstering resilience against disasters, especially floods. The foundation of this discussion is rooted in the definition of resilience as articulated during a workshop that applied the community disaster resilience framework.

This robust assessment tool encompassed four critical domains, and the methodology enabled us to assess the Dominican Republic's preparedness across a spectrum of disaster-related aspects, including anticipation, preparation, response, recovery, and adaptation. These evaluations considered a wide array of factors, encompassing physical, economic, environmental, and social dimensions.

Santo Domingo, akin to many urban centers, confronts an array of challenges. These encompass an aging infrastructure in dire need of maintenance, a dearth of public awareness and education pertaining to disaster preparedness, haphazard urban planning and

land utilization, and significant economic disparities. Nonetheless, within these challenges lies the potential for technological solutions, such as predictive maintenance, intelligent drainage systems, insurance for flooding, and policies that can fortify the city's resilience. Furthermore, the framework provided helps guide the steps for applying any type of live action towards fast-paced recovery systems. The perspective of resilience dividends will ontologically support the justification of some investments for long-term measurements. Furthermore, this framework lays the groundwork for several promising advancements in the Caribbean, e.g., harmonizing international insurance policies, fostering academic collaboration, bridging the language barrier in knowledge sharing, establishing a regional disaster management innovation hub, and unifying disaster risk reduction (DRR) platforms. However, addressing the gaps in general DRR knowledge, particularly in flood management, remains a critical challenge. The Dominican Republic specifically requires a dedicated technological platform for DRR education. Further work is required to expand this study in Caribbean countries.

Throughout this discourse, the paramount significance of community engagement and readiness has been prominently emphasized. This study gleaned invaluable insights from the United Kingdom, where best practices in flood risk management have been honed through real-world experiences. These practices, rooted in practical wisdom, provide tangible guidance for regions like the Dominican Republic grappling with flood-related issues. Above all, this paper underscores the pivotal importance of collaboration among governmental authorities, academia, and society. Such constructive collaboration serves as the linchpin for navigating the intricate landscape of disaster management and community resilience in the city of Santo Domingo. Further works are suggested in developing online disaster management platforms to scale the preparedness and resilience internationally.

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