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Pre-disaster and response activities in disaster management: Insights from an experts' survey and document analysis

Actividades previas y de respuesta a desastres: conclusiones de análisis documental y opiniones de expertos

Diana M. Rodríguez-Coca [1], **Julián Alberto Espejo-Díaz** [2*], **William Javier Guerrero** [2]

[1]Fire Protection & Safety Engineering Technology , College of Engineering, Architecture and Technology, Oklahoma State University. Oklahoma State University Stillwater. C. P. 74078. Stillwater Oklahoma, United States.

[2]Grupo de Investigación en Sistemas Logísticos, Facultad de Ingeniería, Universidad de La Sabana. Campus del Puente del Común km. 7 Autopista Norte. C. P. 250001. Bogotá, Colombia.

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ABSTRACT: Emergencies, disasters, and catastrophes require urgent attention from communities and governments to both prevent and mitigate their impacts. Disaster management is a field of academic research and practical application that encompasses a comprehensive range of activities divided into three main phases: pre-disaster (preparedness and mitigation), response, and recovery. The pre-disaster phase includes efforts such as risk assessments as well as emergency planning and preparedness, while the response phase includes activities such as aid delivery. In this paper, the authors analyze how pre-disaster and response activities impact societies differently when facing various kinds of catastrophes. Specifically, scientific articles and official disaster management reports were reviewed to develop a document analysis that focuses on the pre-disaster and response operations performed in four different types of catastrophes: nuclear power plant accidents, volcanic eruptions, hurricanes, and landslides with distinct features around the world. Next, the study presents an experts' survey and compares the findings with the document analysis. The results show that adequate and sufficient efforts in pre-disaster activities have a more significant impact on preserving lives and reducing the economic impact of catastrophes than response activities. Nevertheless, both pre-disaster and response activities are essential in confronting catastrophes and should be carried out. Operations managers working in humanitarian logistics should direct efforts and resources toward developing effective pre-disaster strategies in areas vulnerable to these risks.

RESUMEN: Emergencias, desastres y catástrofes son problemas que requieren de la atención tanto de las comunidades y los gobiernos para prevenir y mitigar sus impactos. La gestión de desastres es un campo de investigación y aplicación práctica que estudia actividades que comprenden tres áreas principales: pre-desastre (preparación y mitigación), respuesta y recuperación. La fase de pre-desastre incluye esfuerzos como evaluación de riesgos y preparación ante emergencias, mientras que la frase de respuesta incluye actividades como entrega de ayudas. En este artículo, los autores analizan cómo las actividades previas al desastre y de respuesta tienen diferentes impactos en la sociedad cuando se enfrentan a distintas catástrofes. Para ello, se realizó una revisión de artículos científicos y reportes oficiales para construir un análisis documental centrado en las operaciones previas al desastre y de respuesta en los siguientes tipos de catástrofes: accidentes de plantas nucleares, erupciones volcánicas, huracanes y deslizamientos de tierra alrededor del mundo. Posteriormente, se presentan los resultados de una encuesta hecha a expertos para comparar los hallazgos con el análisis documental. Los resultados muestran que las actividades de mitigación y preparación realizadas adecuadamente tienen un impacto más significativo que las actividades de respuesta.

* Corresponding author: Julián Alberto Espejo-Díaz
E-mail: julianesdi@unisabana.edu.co
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Sin embargo, ambos tipos de actividades son esenciales y deben ser realizadas para enfrentar catástrofes. En consecuencia, los planeadores de operaciones en logística humanitaria deben concentrar esfuerzos en establecer estrategias de pre-desastre efectivas especialmente en áreas vulnerables.

1. Introduction

Emergencies, disasters, and catastrophes are events that require the attention of humanitarian agencies, communities, private companies, and governments to prevent and overcome them, while minimizing human suffering. As pivotal elements of human history, these events provide valuable lessons that enhance our resilience and better prepare societies to handle future challenges. For example, in 2017, the United States was affected by a series of hurricanes Harvey, Irma, and Maria being the most severe. In the same year, the economic impact triggered by those and other natural disasters in the United States was estimated at US$306.2 billion [1]. In addition, in 2022, 18 natural disasters in the US resulted in at least US$1 billion in damages [2].

Disaster management aims to minimize the negative impacts of these types of events. [3] defines disaster management as "the management of risk in order to protect life and property through a comprehensive effort that involves activities tied to mitigation, preparedness, response, and recovery." Current research presents multiple variations of this definition, breaking it into activities and/or phases. According to [4], [5], two phases of disasters exist: pre-disaster and post-disaster. However, the study lists pre-disaster but separates post-disaster into response and reconstruction activities. In another example, [6] present preparedness, response, recovery, and evaluation as activities. Moreover, [7] summarize the information flow in the mitigation, preparation, response, and rehabilitation phases of a disaster. Due to this lack of agreement, a standard definition of disaster management is yet to be agreed upon. As [8] explains, the phases of a disaster play a key role in the disaster management field for both researchers and practitioners. In addition, [8] presents eight key ideas that should be considered in defining the disaster phases.

Regardless of how we choose to define disaster management, disasters pose a continuous threat to the world. By studying them, researchers and policymakers can better understand their causes, impacts, and patterns, which can lead to the development of effective mitigation strategies [9].

While defining a disaster management funding strategy, decision-makers need to allocate resources to multiple activities. Naturally, when there are limited monetary resources, they need to decide how much to invest in pre-disaster activities versus post-disaster activities. Studies show that for every US dollar spent on mitigation (part of pre-disaster activities), between US$4 and US$7 can be saved when a disaster strikes [10]. The validity of this estimation has been criticized and opposing results have been found in [11]. The effectiveness of pre-disaster activities is highly uncertain due to the unpredictable nature of a disaster's location, timing, type, and severity. On the other hand, response activities oftentimes are only effective if they are performed within 72 hours after the disaster occurs [12].

This article examines the societal impacts of conducting pre-disaster and response activities. We compared eight disasters—two nuclear power plant accidents, two volcanic eruptions, two hurricanes, and two landslides—by analyzing their pre-disaster and response activities to draw managerial conclusions. The decision to focus solely on pre-disaster and response activities while excluding other activities in the disaster management cycle, such as recovery or rehabilitation, is justified by the following reasons. First, the study aims to provide specific and targeted policy recommendations for improving the development of pre-disaster and response mechanisms. Second, the information provided in the scientific literature on disaster management and other sources usually focuses primarily on these types of activities. Last, there is practical relevance in understanding how communities, governments, and organizations can better prepare for and respond to disasters. This is particularly important since each activity has different costs, benefits, risks, and requirements for the agencies and groups affected by the disaster. Although other activities like rehabilitation also significantly impact societies, their long-term nature makes it more challenging to assess their effects and gather data on their outcomes. Thus, we propose that future research focus on the rehabilitation stage of the disaster management cycle.

While pre-disaster activities can be methodically planned and coordinated with communities and stakeholders over an extended period, the assessment of disaster impacts often remains unclear, ambiguous, and fraught with significant uncertainties. Conversely, response activities require rapid planning and execution under constrained resources, usually with some understanding of the disaster victims' locations and specific needs.

Further, it is crucial to examine the relationship between the different phases of a disaster and their societal impacts. Understanding this relationship can lead to a more effective allocation of financial and human resources. In this paper, we first provide fundamental definitions to contextualize the reader. Then, we analyze the pre-disaster and response activities that were carried out during nuclear power plant accidents, volcanic eruptions, hurricanes, and landslides. We study eight cases—two catastrophes of each type in different regions of the world—and analyze the impacts of pre-disaster and response activities. The analysis includes a survey given to experts about each case, detailing the fatality rate and total costs of damages for each disaster broken down by pre-disaster and response activities. We use these indicators, which are the most common measures in databases such as The International Disaster Database [13] for estimating the outcomes of disaster management. Thus, we acknowledge the study's limitation in obtaining other measures to evaluate the impacts of disaster management operations in other dimensions. The contribution of this article is twofold. First, the paper presents a document analysis that provides insights about the societal impacts of pre-disaster and response activities on disaster outcomes. Second, the paper presents an experts' survey that validates the importance of pre-disaster and response activities.

The rest of the article is organized as follows. Section 2 presents the definitions of key terms used extensively in the document. Section 3 introduces the methodology. Section 4 presents the document analysis of the eight catastrophes analyzed. Section 5 presents the main results of the research, and section 6 provides the conclusions and suggests future research work.

2. Theoretical framework

The following are the fundamental definitions that were used to create our document analysis and experts' survey. These concepts are sometimes used interchangeably in the scientific literature. Thus, we need to provide a standard definition that we use throughout our document analysis and survey application.

2.1 Disaster

The United Nations Office for Disaster Risk Reduction [14] defines disaster as "A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources." Additionally, according to [15], the literature identifies two types of disaster definitions. The first attributes the cause of disasters to physical hazards. The second, as [15] highlights, emphasizes a strong connection between politics and disasters.

2.2 Catastrophe

According to [16], catastrophes are events with significant and severe consequences that result in extensive and debilitating effects, severely hindering the affected society's capacity to respond. These events vary in magnitude, from situations where the affected country can manage independently to those requiring external assistance at a regional or global level. [17] identifies six key points that represent the differences between disasters and catastrophes. First, catastrophes cause significant damage to local infrastructure. Second, emergency teams face challenges in performing their duties. Third, the availability of basic resources is diminished. Fourth, normal community routines are interrupted. Fifth, the presence of news associations rises. Finally, the situation's management becomes politicized.

2.3 Disaster management cycle

As mentioned above, the literature identifies different disaster management phases. In this article, we refer to the disaster phases: mitigation, preparedness, response, and recovery proposed in [18]. We group the mitigation and preparedness phases as pre-disaster activities. In particular, we consider pre-disaster activities as those that involve reducing or eliminating the risk or the likelihood of the disaster happening. For example, radiation monitoring and early warning systems at nuclear facilities are essential pre-disaster activities. According to [19], implementing a disaster risk reduction strategy, including an early warning system for extreme weather events, is crucial as a planning tool and instrument for managing and mitigating higher risks. As another example, land use planning and zoning are considered pre-disaster strategies for volcanic eruptions. Conversely, response activities are defined as those that occur immediately after a disaster strikes, aiming to address immediate needs and reduce the harm to communities. The final phase of disaster management—recovery, which focuses on activities that help the affected community adjust to its new normality, was not considered in this research.

3. Methodology

3.1 Document analysis methodology

After agreeing on the fundamental definitions, we reviewed the literature with the aim of characterizing the pre-disaster and response activities developed in each studied catastrophe. Figure 1 summarizes the document analysis methodology followed in this study. Based on previous results, nuclear facilities, hurricanes, volcanic eruptions, and landslides were selected for analysis. This

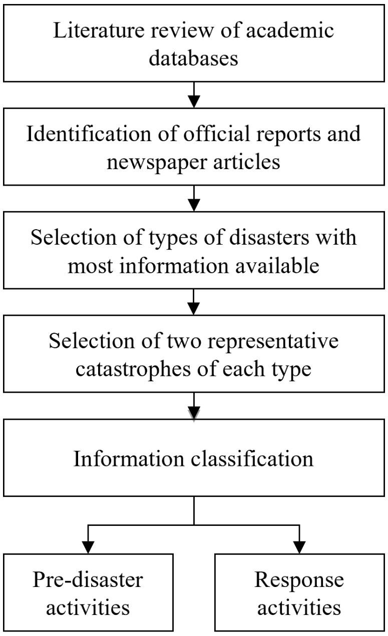

Figure 1 Document analysis methodology

is because sufficient information was available for the analysis. Next, we identified two specific catastrophes for each disaster type based on two criteria. First, the catastrophe must have a significant number of deaths and economic losses compared to the annual mean values for these outcomes. Second, the catastrophe must have documentation of the response and pre-disaster activities. The selected catastrophes were Chernobyl - Ukraine and Fukushima - Japan (nuclear facilities), St. Pierre - Martinique and Armero - Colombia (volcanic eruptions), Katrina – United States and Andrew – United States (hurricanes), and Mocoa - Colombia and Vargas - Venezuela (landslides). Finally, we classified and analyzed the pre-disaster and response activities for the eight selected catastrophes.

3.2 Experts' survey methodology

For the experts' survey, we asked humanitarian logistics experts to assess the pre-disaster and response activities of the eight catastrophes based on their own knowledge of the event. To do so, we created a survey (presented in Appendix 1.a.) asking them to score the performance of pre-disaster and response activities in each catastrophe using the scale presented in Table 1.

The survey was self-administered, and no economic compensation was provided for participating. We contacted experts who participated in the III Symposium on Humanitarian Logistics & Disruptive Supply Chains and alumni of the Fire Emergency Management Program at Oklahoma State University via mail with a link to the survey. A total of 12 experts responded to the survey.

Table 1 Scale for pre-disaster activities and response activities

Score	Description
0	Nonexistent
1	Ineffective
2	Moderately Effective
3	Effective

According to [20], [21], conducting interviews within homogeneous groups, such as experts in humanitarian logistics, does not require a large number of interviews. Therefore, we believe that the survey can provide valuable insights into the pre-disaster and response activities of the catastrophes under study.

4. Document analysis

4.1 Nuclear catastrophes

We chose two examples of large nuclear facility accidents from the literature: Chernobyl (1986) and Fukushima (2011) [22–24]. Here, we present an analysis of both nuclear accidents from the perspectives of pre-disaster and response activities, followed by concluding remarks.

Chernobyl

On April 26, 1986, during a technical test at Reactor 4 of the Chernobyl Nuclear Power Plant, a nuclear accident occurred [25]. According to the report "Chernobyl: the true scale of the accident" from the World Health Organization [26], approximately 4,000 people died from direct radiation exposure. Moreover, 350,000 people were relocated out of the affected area. Notably, [24] and [27] concluded that the principal cause of the Chernobyl catastrophe was a design error. Other researchers suggest that lack of knowledge and training was the main cause of the accident [24, 27–29]. Moreover, [23] mentions that both human error and technical problems contributed to the nuclear accident. The literature identifies safety systems and construction codes as pre-disaster measures for a nuclear plant, and the International Atomic Energy Agency (IAEA) [28] highlights that Chernobyl had these safety systems in place. However, [24] indicates that safety systems are not capable of overcoming all possible situations. As part of the response phase of the Chernobyl accident, activities such as evacuation, reactor protection using special materials [28], [30] are considered adequate response measures.

Fukushima

On March 11, 2011, a 9.0 magnitude earthquake struck Japan, triggering a tsunami that inundated and flooded the Fukushima Daiichi nuclear power plant. It caused the failure of several systems that led to nuclear meltdowns, oxy-hydrogen gas explosions, and the release of radioactive contamination [25]. According to [31], most of the 1,914 deaths at the Fukushima prefecture at that time were attributable to the nuclear accident. In addition, [32] reports that approximately 164,000 people were evacuated from nearby areas. Moreover, [24, 33, 34] concluded that human errors caused the Fukushima nuclear accident. Regarding the safety systems and construction codes as pre-disaster measures for a nuclear plant, [33] highlights the inclusion of designs resistant to seismic activity. On the other hand, [24, 33, 34], note the lack of tsunami-related pre-disaster activities at the Fukushima plant. According to [33], the Fukushima catastrophe response phase was inadequate. In addition, [33] attributes the inadequacies of response activities to the deficiencies in crisis management and leadership, as well as the improper application of safety regulations.

Remarks

Notably, [35] concludes that the consequences of a radioactive accident could be reduced with better pre-disaster activities. For example, [36, 37] suggest choosing an optimal location for a nuclear plant, and [29] suggests using simulators for nuclear processes. Evidently, both the Chernobyl and Fukushima catastrophes had pre-disaster and response activities in place. However, research has revealed problems with the activities implemented in both phases. A significant factor contributing to these issues is the lack of understanding about potential disaster scenarios.

Volcanic eruptions

The International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED) identifies the volcanic eruptions in Saint-Pierre, Martinique (1902) and Armero, Colombia (1985) as the two most deadly between 1900 and 2013 [38]. As a result of the volcanic eruptions, approximately 29,000 people died in Martinique and 21,800 in Colombia [30, 38, 39]. In addition, [40] indicates that Central America and Colombia are among the regions with the highest population density near dangerous volcanoes. Here, we present an analysis of both volcanic eruptions from the perspectives of pre-disaster and response activities, followed by concluding remarks.

Armero

On November 13, 1985, the Nevado del Ruiz volcano, located in the area of Tolima, Colombia, erupted causing devastating damage to nearby towns and destroying the Armero municipality [41]. This volcanic eruption was one of the deadliest catastrophes in the region, causing approximately 22,000 deaths and affecting an estimated 230,000 people [38, 42]. Given the known location of the volcano, it is best practice for the surrounding populations to have an emergency plan. Implementing these emergency plans can be considered as a pre-disaster activity, according to the literature. A key component of this plan is the timely alerting of people when evacuation is necessary. Recognizing the imminence of a dangerous situation is essential for this to be effective. Notably, in Armero, authorities informed residents that evacuation was not necessary [43].

The creation of hazard maps is also regarded as a pre-disaster measure [18]. [44] acknowledges that a hazard map existed before the Armero catastrophe. However, Armero was not marked as a dangerous area on that map [44]. It should be noted that this location had experienced the same natural disaster in 1595 and 1845, as reported by [45]. In addition, [41, 44, 46] suggest the placement of multiple pieces of equipment to monitor the activity of the Armero volcano as another pre-disaster measure. However, not all of this equipment was in place before the eruption. Further, [44] reports that there was no communication between the authorities ahead of the catastrophe. In fact, [47] reports that the disaster could have been avoided or mitigated had communication taken place. In addition, [43] further presses the point that there was no communication between authorities even after the volcano erupted, which means that any response activities that may have taken place were not coordinated. Moreover, [15] suggests that a lack of coordination was one of the most significant factors contributing to the inadequate response activities following any type of event.

Saint-Pierre

In May 1902, Mount Pelée erupted multiple times, causing a violent pyroclastic current that overtook the city of Saint-Pierre, Martinique. This catastrophe is considered the deadliest volcanic eruption of the last century [39]. According to [48], the pyroclastic current destroyed the city, killing nearly all of its 29,000 citizens. As noted before, one crucial activity in the pre-disaster phase is to alert people when evacuation is necessary. As with the Armero disaster, Martinique authorities told the citizens of Saint-Pierre that evacuation was not necessary [49–51]. However, the research of [50] and [52] does point out that resources were sent to nearby towns as part of the response phase, which saved those citizens affected by the disaster from starvation.

Remarks

The total number of casualties from the Martinique and Armero catastrophes was approximately 51,800 people. The principal reason for the high death toll is that authorities did not carry out evacuation activities before the eruption. Therefore, we believe that pre-disaster activities could have saved lives in the areas where the volcanoes erupted, whereas the response activities did not.

Hurricanes

Hurricanes Andrew and Katrina struck the United States in 1992 and 2005, respectively. [53] acknowledges that Hurricane Katrina was a catastrophe. Similarly, the National Weather Service identified Hurricane Andrew as a catastrophe [54]. Here, we present an analysis of both hurricane catastrophes from the perspectives of pre-disaster and response activities, followed by concluding remarks.

Andrew

In August 1992, a category 5 hurricane named Andrew impacted Florida and Louisiana in the United States, as well as the Bahamas. According to [55] and the National Centers for Environmental Information [56], the hurricane caused 65 deaths and left 250,000 people homeless. The work of [57] notes that pre-disaster activities, such as the pre-location of relief supplies, were necessary to prepare for Hurricane Andrew. Additionally, both Sirkin [57] and the National Weather Service [54] emphasize that pre-disaster activities, including warning systems and the evacuation process, were correctly implemented before Hurricane Andrew struck.

Conversely, [57] identifies the lack of effective and efficient response activities carried out after the hurricane as a major factor contributing to the severity of the catastrophe. In addition, [58] concluded that communication between relevant stakeholders was a primary concern during the response phase. Furthermore, [57] indicated that the lack of appropriate equipment was another issue during the response phase. Lastly, [57] noted that it was impossible for local emergency agencies to operate from their headquarters after the hurricane occurred.

Katrina

In August 2005, a category 5 hurricane named Katrina impacted multiple states in the United States (mainly Louisiana, Mississippi, and Alabama), and other countries such as the Bahamas and Canada. The impacts were primarily due to high winds, flooding, and a storm surge. According to a U.S. Congressional Research Service report [59], an estimated 700,000 people were acutely affected by the hurricane. A study by Welch and Taylor [50] reports 1,833 deaths attributed to the Katrina hurricane. Additionally, [60] indicates that Hurricane Katrina affected emergency management facilities, suggesting that authorities engaged in pre-disaster activities in the impacted area. Examples of these activities include the pre-location of supplies and agreements with emergency suppliers. However, the authors emphasize that these measures did not function as intended.

On the response side, [61] highlights the lack of response activities as a major factor contributing to the severity of the catastrophe. Similarly to the response to Hurricane Andrew, [53, 62] identify the breakdown in communication between authorities as one of the biggest issues during the response phase. Additionally, [53] identifies the lack of equipment as another problem contributing to this catastrophe. Further, according to [61], disaster agencies were heavily impacted by the hurricane and were not able to operate from their headquarters.

Remarks

The works of [57, 63] suggest developing pre-disaster activities as a requirement for mitigating the societal effects of hurricanes. As part of these pre-disaster activities, the National Weather Service [54] recommends the implementation of building codes to reinforce structures in areas vulnerable to hurricanes. It is important to note that the report limits the implementation of these building codes to the coast. In addition, the report mentions that pre-disaster policies are needed. Notably, multiple agencies developed pre-disaster and response activities for Hurricane Andrew and Hurricane Katrina. However, these agencies were not able to communicate after the hurricanes struck their headquarters, which created significant communication issues during the response processes. One way to avoid this issue might be for agencies to build their headquarters in areas that are not likely to be affected by the disaster.

4.2 Landslides

The United States Geological Survey (USGS) defines landslides as "movements of a mass of rock, debris, or earth down a slope under the direct influence of gravity" [64]. Landslides include five modes of movement: falls, topples, slides, spreads, and flows. We study two recent landslides the 2017 Mocoa-Colombia landslide and the 1999 Vargas-Venezuela landslide. Here, we analyze them and provide concluding remarks based on their pre-disaster and response activities.

Mocoa

The landslide of Mocoa, Colombia in 2017 is one of the deadliest catastrophes of recent Colombian history. On the night of March 31, 2017, and into the early hours of April 1, heavy rains in the Putumayo region caused the Mulata, Sangoyaco, and Mocoa rivers to overflow. This caused multiple landslides that vastly affected the urban area of Mocoa, killing 332, injuring 330, and causing the disappearance of more than 100 [65]. In addition, the landslide displaced 22,000 people and 17 neighborhoods [65, 66]. There are many pre-disaster measures to take to mitigate the effects of a landslide, including installing structures such as pile or retaining walls, modifying the slope geometry, or grouting rock joints. Notably, [67] concluded that pre-disaster measures were absent in Mocoa prior to the catastrophe. Moreover, [68] and [69] note that this region had a history of challenging socioeconomic conditions and had been deeply marked by the Colombian civil conflict, which contributed to the lack of pre-disaster efforts. On the other hand, [67] describes the response activities as significant. Shelter facilities were set up to provide assistance to the most affected families in surrounding neighborhoods. According to a Colombian Red Cross situation report [70], the response phase included significant search and rescue efforts, the installation of shelters and tents, providing potable water, improvements to medical facilities, and the reestablishing of telecommunications.

Vargas

Another set of deadly landslides occurred in Vargas, Venezuela in 1999. On that occasion, a heavy storm began on December 14 and ended on December 16, causing devastating landslides and floods in the State of Vargas, Venezuela [71]. The Vargas tragedy is considered one of the deadliest catastrophes in Venezuelan history. It took the life of an estimated 19,000 people, and left thousands injured and missing [72]. Other studies such as [73] estimate the number of casualties to be between 15,000 and 50,000. According to [74], there were little to no pre-disaster measures in place. In particular, [74] highlights the lack of adequate hydraulic infrastructure, early warning systems, evacuation plans, and the absence of pluviometric stations as fundamental factors that contributed to the severity of the catastrophe. Notably, [75] reports that 18 similar events had been recorded between 1942 and 2017 in the same location. Additionally, [75] explains that the morpho dynamic activity in Vargas increases the risk to the communities settled on it. Knowing this, it would be prudent for authorities to put structural and non-structural pre-disaster solutions in place. Regarding the response phase, [73] mentions that there were not enough technical or methodological resources to face an emergency of this magnitude. Moreover, [76] reports that the Venezuelan CUFAN (Comando Unificado de las Fuerzas Armadas Nacionales) oversaw the response phase, while the local and regional authorities were ignored. In other words, the Venezuelan army had full control over the response phase. According to [77], this led to human rights violations, as well as poor coordination and logistic inefficiencies among international aid agencies. Unlike the Mocoa, Colombia catastrophe, in which most of the people affected were victims of the civil conflict who had challenging economic conditions, those affected by the Vargas landslide came from all economic levels. This is an important distinction to make because [76] reports that during the response phase of the Vargas landslide, two groups of victims were identified. The first group, consisting of individuals with sufficient financial resources, found provisional shelter and housing with relatives or friends in Caracas or other parts of the country. In contrast, the second group lived for months in improvised shelters at military barracks.

Remarks

In both landslide catastrophes, pre-disaster activities were almost nonexistent. The absence of methodologies to measure and assess the severity of heavy storms resulted in no evacuations prior to the landslide. In addition, the literature indicates that the lack of active early warning systems, inadequate disaster risk reduction measures such as the installation of piles or walls, and the absence of evacuation plans contributed to the high number of casualties in both catastrophes.

4.3 General document remarks

The findings from the landslide analysis align with those of previous catastrophes, indicating that pre-disaster activities have a more significant impact on communities compared to extensive response activities. To summarize the impact of each catastrophe, Table 2 presents the total death toll and the number of affected individuals for each catastrophe and calculates the case fatality rate. This concept, adapted from epidemiology, measures the ratio of deaths to the number of affected individuals [78]. In this study, the case fatality rate is used to assess the death toll in relation to the number of affected people. Additionally, Table 2 includes the total estimated damages in adjusted value.

As shown in Table 2, the volcanic eruption in Saint-Pierre, Martinique has the highest case fatality rate. This is likely because the eruption occurred in 1902, a time when pre-disaster activities were nearly nonexistent. In contrast, the Vargas landslides of 1999, which have the second-highest case fatality rate, are harder to explain due to deficiencies in both pre-disaster and response activities. It is important to note the significant difference of 0.7 points between the two highest case fatality rates, suggesting an evolution in the disaster management field.

5. Survey Analysis

As mentioned above, the survey's main objective was to ask humanitarian logistics experts to assess the

Table 2 Death tolls and numbers of affected people, case fatality rates, and total estimated damages for each catastrophe

Catastrophe	Year	Country	Death toll / Estimated number of people affected	Case fatality rate	Total estimated damages (in USD '000 adjusted value)
Chernobyl	1986	Ukraine (former Soviet Union)	4,000 / 350,000 [26]	0.011	$6,922,056 [38]
Fukushima	2011	Japan	1,914 / 164,000 [31, 32]	0.011	$187,000,000 [79]
Saint-Pierre	1902	Martinique	28,998 / 29,000 [48]	0.999	Not available
Armero	1985	Colombia	21,800 / 230,000 [38, 42]	0.096	$2,519,086 [38]
Andrew	1992	United States	61 / 250,000 [55, 56]	0.0002	$51,174,936 [38]
Katrina	2005	United States	1,833 / 700,000 [59, 60]	0.002	$173,439,092 [38]
Mocoa	2017	Colombia	332 / 22,000 [65]	0.015	$110,546 [38]
Vargas	199	Venezuela	19,000 / 90,000 [72, 80]	0.211	$5,140,412 [38]

Table 3 Experts' survey responses

Pre-Disaster Activities						
Disaster/Score	0	1	2	3	Individual Average	Group Average
Chernobyl	4	6	2	0	0.83	1.00
Fukushima	1	8	3	0	1.17	
Saint-Pierre	12	0	0	0	0.00	0.25
Armero	6	6	0	0	0.50	
Andrew	0	1	4	7	2.50	1.84
Katrina	0	10	2	0	1.17	
Mocoa	5	7	0	0	0.58	0.50
Vargas	7	5	0	0	0.42	
Response Activities						
Disaster/Score	0	1	2	3	Individual Average	Group Average
Chernobyl	1	5	4	2	1.58	1.63
Fukushima	1	2	9	0	1.67	
Saint-Pierre	9	3	0	0	0.25	0.63
Armero	2	8	2	0	1.00	
Andrew	0	5	7	0	1.58	1.41
Katrina	1	7	4	0	1.25	
Mocoa	0	0	4	8	2.67	1.59
Vargas	7	4	1	0	0.50	

pre-disaster and response activities of the eight analyzed catastrophes. Table 3 presents frequencies and average scores for pre-disaster and response activities.

As observed in Table 3, hurricanes have the highest average scores for pre-disaster activities. This was expected since technology exists that allows for the early identification of this natural phenomenon. With regard to pre-disaster activities, one expert mentioned that, "Pre-staging of supplies was located in the [hurricane] disaster area for the most part, which is not conducive to effective emergency response and recovery." From response activities, hurricanes did not obtain the highest average score. One expert mentioned that "*The confluence of historic development, poverty, racial tension, politics and media amplification resulted in an almost complete (response) failure.*" A different expert highlighted that, "*Communication is typically a major failure point in response.*"

Nuclear facility catastrophes obtained the highest response activities average score. However, experts provided remarks about issues with response activities for these catastrophes, such as "*The concept of cascading disasters was poorly understood*" and "*Socio-political factors were also significant.*" With respect to pre-disaster activities, experts point out that, "*Due to the nature of operations at the Chernobyl site, contingency measures should have been implemented to counteract issues resulting from human error.*" "*With regard to both mitigation and response: an all-hazards approach to crisis management and leadership was not utilized, thus providing additional vulnerability to seismic activity resulting in a tsunami.*" Analyzing individual scores, there are two outliers. First, the landslide in Mocoa, Colombia scored highest for response activities but received a low score for pre-disaster activities. One expert highlighted the "*interesting disparity between mitigation and response.*" Second, the Saint-Pierre, Martinique volcanic eruption obtained a 0.0 score for pre-disaster activities. An expert commented that "*Looking back 120 years, [pre-disaster activities] may be difficult given the infancy in seismology research and communications.*" The relationship between the experts' survey results and the fatality rate is presented in Figure 2. The size of each bubble corresponds to the case fatality rate for each catastrophe. Different conclusions can be drawn from the information in Figure 2. First, we identify three cases—the Vargas landslide, the Mocoa landslide, and the Fukushima nuclear accident. The Vargas landslide is characterized by a large fatality rate after little to no pre-disaster or response efforts. The Mocoa landslide is characterized by a significant set of response activities that did not improve the fatality rate. Finally, the Fukushima nuclear accident had several pre-disaster activities and substantial response activities, which could be responsible for a lower fatality rate than other catastrophes. Additionally, the high fatality rate in the Armero volcanic eruption can primarily be attributed to the lack of pre-disaster activities, such as the failure to evacuate the population, as authorities had informed

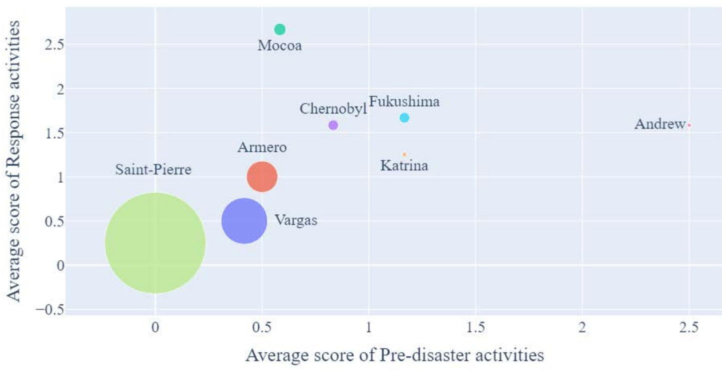

Figure 2 Analysis of catastrophes by pre-disaster and response activities scores, and case fatality rate

residents that evacuation was not necessary. In general, we surmise that higher case fatality rates are present in catastrophes with nonexistent or few and ineffective pre-disaster activities. The case fatality rate seems to decrease when pre-disaster activities were carried out. For response activities, there is no apparent influence on the fatality rate indicator. However, these activities are crucial in the aftermath of catastrophes to save lives and improve the well-being of victims.

These findings are consistent with the document analysis, where pre-disaster activities are more effective in saving lives than response activities. Consequently, there is evidence to suggest that pre-disaster activities have a profound impact on the outcome of a catastrophic event. Meanwhile, response activities help to alleviate human suffering after a catastrophe, but their effectiveness is limited by the complexity of the disaster and the need to be performed within a specific timeframe.

Figure 3 illustrates the relationship between the damage caused by each catastrophe from a cost perspective and the results of the experts' survey. The size of each bubble represents the damage-adjusted total cost of each disaster. The figure shows no clear trend between the pre-disaster and response scores and the total estimated damages. The economic value of the damages is influenced by various factors, including location, type, and intensity of the disaster. Consequently, we conclude that for the studied cases, mitigation and response activities were more focused on protecting lives rather than infrastructure.

6. Conclusions

In this article, we examined four types of catastrophes to gather lessons learned and identify significant differences and similarities among them. We reviewed documents analyzing nuclear facility accidents, volcanic eruptions, hurricanes, and landslides. The research aims to assess the impact of pre-disaster and response activities across various catastrophes. We recognize that the effectiveness and efficiency of these activities differ in each case and depend heavily on the risk assessment and the available resources and technology for disaster relief efforts.

According to the catastrophes we analyzed, those with significant pre-disaster activities had better outcomes than those with little to no pre-disaster measures in place, and where authorities relied mostly on response activities. There are many pre-disaster activities that can be put in place to mitigate the societal effects of future catastrophes. For instance, first responder trainings in technical topics as well as in disaster management can significantly reduce these impacts. In addition, evacuation plans should be put in place in every area that could be affected by a disaster. Additionally, practitioners and government agencies should learn from past experiences. In particular, disaster management agencies should build their headquarters in strategic locations, near but not in disaster-prone areas.

In addition to the document analysis, we used an expert survey to assign scores for pre-disaster and response activities. We then correlated these scores with the case fatality rate for each catastrophe. From the analysis we can conclude that catastrophes with higher scores on pre-disaster activities result in smaller case fatality rates. Nevertheless, it is important to highlight that it is impossible to predict every disaster and its consequences, meaning that authorities must also focus on preparing response activities. As [81] points out, "There can be no experience for some of the future disasters we may expect."

One limitation of our study is the amount of available information on catastrophes that occurred many years ago, especially before the year 2000. For these cases, documentation providing disaster relief operations is

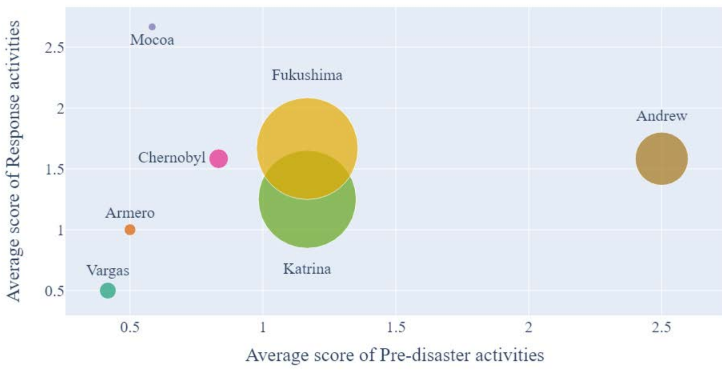

Figure 3 Analysis of catastrophes by pre-disaster activities, response activities, and damages adjusted by cost

scarce [82]. For more recent events, while there is more readily available information, some official reports only provide incomplete data and the details of logistic operations are oftentimes vague. For these cases, research about the location of the disaster is required.

For future research, it would be valuable to consider additional aspects. First, researchers might study how the differences between a disaster and a catastrophe could affect the conclusion of this study. Second, the learning and return-entry processes should be analyzed by comparing multiple events. For instance, [83] studied what motivated municipalities in Norway to learn from disasters and how they implement these lessons. Lastly, it may also be important to assess how new technologies, such as unmanned aerial vehicles, autonomous vehicles, robots, internet-of-things, social networks, and other disruptive technologies, are changing the societal impacts of disaster mitigation and response operations.

7. Appendix A.

7.1 Survey

We are analyzing mitigation and response teams' activities for nuclear facilities, volcanic eruptions, hurricanes, and landslide catastrophes. Based on your expertise in the following situations, could you assess the mitigation and the response activities of these catastrophes using the scale below? The score ranges from 0 to 3 as follows.

- 0 Nonexistent
- 1 Ineffective
- 2 Moderately Effective
- 3 Effective

Disaster	Score Mitigation	Response	Brief justification for your score
Chernobyl - 1986 Ukraine			
Fukushima - 2011 Japan			
St. Pierre -1902 Martinique			
Armero - 1985 Colombia			
Andrew - 1992 United States			
Katrina - 2005 United States			
Mocoa - 2017 Colombia			
Vargas - 1999 Venezuela			

Declaration of competing interest

We declare that we have no significant competing interests including financial or non-financial, professional, or personal interfering with the full and objective presentation of the work described in this manuscript.

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Author contributions

D. M. Rodríguez-Coca: Conceptualization, methodology, formal analysis, writing original draft; J. A. Espejo-Díaz: Conceptualization, formal analysis, writing original draft: W. J. Guerrero: Methodology, formal analysis

Data availability statement

The authors confirm that the data supporting the findings of this study is available upon request

References

[1] A. B. Smith, "2016: A historic year for billion-dollar weather and climate disasters in u.s. | noaa climate.gov," National Oceanic and Atmospheric Administration, Jan. 09, 2017. [Online]. Available: https://www.climate.gov/news-features/blogs/beyond-data/2016-historic-year-billion-dollar-weather-and-climate-disasters-us

[2] N. C. for Environmental Information (NOAA), "Billion-dollar weather and climate disasters: Overview," 2021. [Online]. Available: https://www.ncdc.noaa.gov/billions/

[3] B. D. Phillips, "Disaster as a discipline: The status of emergency management education in the u.s." *Int. J. Mass Emerg. Disasters*, vol. 23, no. 1, Mar. 2005. [Online]. Available: https://doi.org/10.1177/028072700502300

[4] B. Balcik, B. Beamon, C. C. Krejci, K. M. Muramatsu, and M. Ramirez, "Coordination in humanitarian relief chains: Practices, challenges," *Int. J. Prod. Econ.*, vol. 126, no. 1, Jul. 2010. [Online]. Available: https://doi.org/10.1016/j.ijpe.2009.09.008

[5] M. Rogge, "The future is now: Social work, disaster management, and traumatic stress in the 21st century," *J. Soc. Serv. Res.*, vol. 30, no. 2, 2004. [Online]. Available: https://doi.org/10.1300/J079v30n02_01

[6] G. Kovecs and K. Spens, "Humanitarian logistics in disaster relief operations," *Int. J. Phys. Distrib. Logist. Manag.*, vol. 37, no. 2, 2007. [Online]. Available: https://doi.org/10.1108/09600030710734820

[7] J. A. Espejo-Díaz and W. J. Guerrero, "A multiagent approach to solving the dynamic postdisaster relief distribution problem," *Oper. Manag. Res.*, Apr. 2021. [Online]. Available: https://doi.org/10.1007/s12063-021-00192-1

[8] D. M. Neal, "Reconsidering the phases of disaster," *Int. J. Mass Emerg. Disasters*, vol. 15, no. 2, Aug. 1997. [Online]. Available: https://doi.org/10.1177/02807270970150020

[9] H. L. Díaz, K. A. Imitola, and R. J. A. Amado, "Perspectivas de investigación en or/ms en la gestión de operaciones de desastres: una revisión de la literatura," *Rev. Fac. Ing. Univ. Antioquia*, vol. 91, 2019. [Online]. Available: https://doi.org/10.17533/udea.redin.n91a05

[10] J. Dunsavage, "Flood: Beyond risk transfer," Insurance Information Institute, 2021. [Online]. Available: https://www.iii.org/white-paper/flood-beyond-risk-transfer-042921

[11] K. H. Goldschmidt and S. Kumar, "Reducing the cost of humanitarian operations through disaster preparation and preparedness," *Ann. Oper. Res.*, vol. 283, no. 1–2, Dec. 2019. [Online]. Available: https://doi.org/10.1007/s10479-017-2587-z

[12] UNHCR, "Unhcr policy on emergency preparedness and response," 2023. [Online]. Available: https://emergency.unhcr.org/emergency-preparedness/emergency-policy/unhcr-policy-emergency-preparedness-and-response

[13] CRED and UCLouvain, "Em-dat," Brussels, Belgium, 2024. [Online]. Available: https://www.emdat.be/

[14] T. U. N. O. for Disaster Risk Reduction, "Terminology on disaster risk reduction," 2021.

[15] J. Hannigan, *Disasters Without Borders*, 1st ed. Polity Press, 2012.

[16] J. Holguín-Veras, M. Jaller, L. N. V. Wassenhove, N. Pérez, and T. Wachtendorf, "On the unique features of post-disaster humanitarian logistics," *J. Oper. Manag.*, vol. 30, no. 7–8, Aug. 31, 2012. [Online]. Available: https://doi.org/10.1016/j.jom.2012.08.003

[17] E. L. Quarantelli, "Emergencies, disasters and catastrophes are different phenomena," Disaster Research Center, 2000. [Online]. Available: http://udspace.udel.edu/handle/19716/674

[18] D. P. Coppola, *Introduction to International Disaster Management*, 2nd ed. Elsevier, 2011.

[19] J. A. Ramón-Valencia, J. R. Palacios-González, G. R. Santos-Granados, and J. D. Ramón-Valencia, "Early warning system on extreme weather events for disaster risk reduction," *Rev. Fac. Ing. Univ. Antioquia*, no. 92, June 2019. [Online]. Available: https://doi.org/10.17533/udea.redin.20190628

[20] A. K. Hagaman and A. Wutich, "How many interviews are enough to identify metathemes in multisited and cross-cultural research? another perspective on guest, bunce, and johnson's (2006) landmark study," *Field Methods*, vol. 29, no. 1, Feb. 2017. [Online]. Available: https://doi.org/10.1177/1525822X16640447

[21] J. Jager, D. L. Putnick, and M. H. Bornstein, "More than just convenient: The scientific merits of homogeneous convenience samples," *Monogr. Soc. Res. Child Dev.*, vol. 82, no. 2, Jun. 2017. [Online]. Available: https://doi.org/10.1111/mono.12296

[22] S. M. Hoffman and A. Oliver-Smith, *Catastrophe & Culture: The Anthropology of Disaster*, 1st ed. Santa Fe, NM: School of American Research Press, 2002.

[23] C. D. Ferguson, "Japan melted down, but that doesn't mean the end of the atomic age," *Foreign Policy*, no. 189, p. 49–53, 2011.

[24] L. Högberg, "Root causes and impacts of severe accidents at large nuclear power plants," *Ambio*, vol. 42, no. 3, 2013. [Online]. Available: https://doi.org/10.1007/s13280-013-0382-x

[25] G. Steinhauser, A. Brandl, and T. E. Johnson, "Comparison of the chernobyl and fukushima nuclear accidents: A review of the environmental impacts," *Sci. Total Environ.*, vol. 470–471, February 2014. [Online]. Available: https://doi.org/10.1016/j.scitotenv.2013.10.029

[26] W. H. Organization, "Chernobyl: the true scale of the accident," 2005. [Online]. Available: https://www.who.int/news/item/05-09-2005-chernobyl-the-true-scale-of-the-accident

[27] R. Wilson, "A visit to chernobyl," *Science*, vol. 236, no. 4809, p. 1636–1640, 1987. [Online]. Available: https://doi.org/10.1126/science.3603003

[28] IAEA, "Information on the accident at the chernobyl nuclear power station and its consequences," *Sov. At. Energy*, vol. 61, no. 5, Nov. 1986. [Online]. Available: https://doi.org/10.1007/bf01122262

[29] J. F. Ahearne, "Nuclear power after chernobyl," *Science*, vol. 236, no. 4802, May. 8, 1987. [Online]. Available: https://doi.org/10.1126/science.3576192

[30] G. A. Thomas, M. D. Tronko, A. F. Tsyb, and R. M. Tuttle, "What have we learnt from chernobyl? what have still to learn?" *Clin. Oncol.*, vol. 23, no. 4, May. 2011. [Online]. Available: https://doi.org/10.1016/j.clon.2011.02.001

[31] A. Hasegawa, T. Ohira, M. Maeda, S. Yasumura, and K. Tanigawa, "Emergency responses and health consequences after the fukushima accident; evacuation and relocation," *Clin. Oncol.*, vol. 28, no. 4, Apr. 2016. [Online]. Available: https://doi.org/10.1016/j.clon.2016.01.002

[32] X. B. Do, "Fukushima nuclear disaster displacement: How far people moved and determinants of evacuation destinations," *Int. J. Disaster Risk Reduct*, vol. 33, pp. 235–252, Feb. 2019. [Online]. Available: https://doi.org/10.1016/j.ijdrr.2018.10.009

[33] Y. Funabashi and K. Kitazawa, "Fukushima in review: A complex disaster, a disastrous response," *Bull. At. Sci.*, vol. 68, no. 2, 2012. [Online]. Available: https://doi.org/10.1177/0096340212440359

[34] I. Suzuki and Y. Kaneko, *Japan's Disaster Governance: How was the 3.11 Crisis Managed?* Springer-Verlag, 2013.

[35] V. Saenko, V. Ivanov, T. Bogdanova, M. Tronko, and *et al.*, "The chernobyl accident and its consequences," *Clin. Oncol.*, vol. 23, no. 4, 2011. [Online]. Available: https://doi.org/10.1016/j.clon.2011.01.502

[36] S. V. Jargin, "Debate on the chernobyl disaster: on the causes of chernobyl overestimation," *Int. J. Heal. Serv.*, vol. 42, no. 1, 2012. [Online]. Available: https://doi.org/10.2190/HS.42.1.c

[37] P. P. Sharma, "Chernobyl & fukushima: Lessons to be learnt," *Indian J. Surg.*, vol. 73, 2011. [Online]. Available: https://doi.org/10.1007/s12262-011-0259-9

[38] C. C. for Research on the Epidemiology of Disasters), "Em-dat," Université Catholique de Louvain, Brussels, Belgium, 2021. [Online]. Available: http://www.emdat.be/

[39] V. Gueugneau, K. Kelfoun, S. Charbonnier, A. Germa, and G. Carazzo,

"Dynamics and impacts of the may 8th, 1902 pyroclastic current at mount pelée (martinique): New insights from numerical modeling," *Frontiers in Earth Science*, vol. 8, Jul. 2020. [Online]. Available: https://doi.org/10.3389/feart.2020.00279

[40] M. Dilley, R. S. Chen, U. Deichmann, A. L. Lerner-Lam, and M. Arnold, *Natural Disaster Hotspots: A Global Risk Analysis*. Washington D.C: The World Bank, 2005.

[41] R. R. Castañeda, "Armero, la negligencia y la incomunicación. una tragedia colombiana en réplica permanente." *EL ESPECTADOR*, November 2010.

[42] W. D. Montalbano, "Three weeks after volcano tragedy colombia shrouded in controversy," *The Citizen, Ottawa*, p. 115, 1985.

[43] J. Treaster, "Rescue teams call for help to save thousands trapped in colombian volcano mud; 'we need people'," *The New York Times*, 1985.

[44] B. Voight, "The 1985 nevado del ruiz volcano catastrophe: anatomy and retrospection," *J. Volcanol. Geotherm. Res.*, vol. 44, no. 3–4, Dec. 1990. [Online]. Available: http://dx.doi.org/10.1016/0377-0273(90)90027-D

[45] D. Hermelin, "Los desastres naturales y los medios en colombia: ¿información para la prevención?" *Gestión y Ambient.*, vol. 10, no. 2, pp. 101–108, Aug. 2007. [Online]. Available: https://repositorio.unal.edu.co/handle/unal/22759

[46] M. L. Hall, "Chronology of the principal scientific and governmental actions leading up to the november 13, 1985 eruption of nevado del ruiz, colombia," *J. Volcanol. Geotherm. Res.*, vol. 42, 1990. [Online]. Available: http://dx.doi.org/10.1016/0377-0273(90)90072-N

[47] O. D. Cardona, "Management of the volcanic crises of galeras volcano: Social, economic and institutional aspects," *J. Volcanol. Geotherm. Res.*, vol. 77, no. 1–4, 1997. [Online]. Available: https://doi.org/10.1016/S0377-0273(96)00102-3

[48] A. Lacroix, "La montagne pelée et ses éruptions," *Bull. Am. Geogr. Soc.*, vol. 1, pp. 60–62, 1904.

[49] C. E. Borchgrevink, "Martinique supplement: History's greatest disaster," *Frank Leslie's Pop. Mon.*, no. 6, 1902.

[50] J. H. Welch and H. E. Taylor, *Destruction of St. Pierre, Martinique*. R.F. Fenno, 1902.

[51] A. Heilprin, "Mont pelee and the tragedy of martinique," *Bulletin of the American Geographical Society*, vol. 35, no. 1, 1903. [Online]. Available: https://www.jstor.org/stable/197555

[52] I. P. Noyes, *The eruption of Mont Pelee and what it suggests*. Washington D. C: The Library of Congress, 1902. [Online]. Available: https://archive.org/details/eruptionofmontpe00noye/page/n1/mode/2up

[53] L. Melnyk, "Katrina lessons learned," *Soldiers*, vol. 61, no. 6, pp. 28–33, 2006. [Online]. Available: https://www.thefreelibrary.com/Katrina+lessons+learned.-a0148056331

[54] N. W. Service, "Hurricane andrew: South florida and louisiana: August 23-26, 1992," U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Md., Tech. Rep., 1993. [Online]. Available: https://repository.library.noaa.gov/view/noaa/7252

[55] D. Victor, "Hurricane andrew: How the times reported the destruction of 1992," *The New York Times*, Sep. 7, 2017. [Online]. Available: https://go.gale.com/ps/i.do?id=GALE%7CA503617193&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=03624331&p=AONE&sw=w&userGroupName=anon%7Ea92494bd&aty=open-web-entry

[56] A. Smith, "1980-2021 u.s. billion-dollar weather and climate disasters," National Oceanic and Atmospheric Administration, Tech. Rep., 2022. [Online]. Available: https://www.researchgate.net/publication/357718529_1980-2021_US_Billion-dollar_weather_and_climate_disasters

[57] A. Sirkin, "Engineering overview of hurricane andrew in south florida," *J. Urban Plan. Dev.*, vol. 121, no. 1, 1995. [Online]. Available: https://doi.org/10.1061/(ASCE)0733-9488(1995)121:1(1)

[58] L. G. Dee, "Lessons learned from hurricane andrew," *J. Am. Vet. Med. Assoc.*, vol. 203, no. 7, 1993. [Online]. Available: https://avmajournals.avma.org/view/journals/javma/203/7/javma.1993.203.07.0986.pdf

[59] G. Falk, T. Gabe, and M. MacCarty, "Hurricane katrina: Social-demographic characteristics of impacted areas," Nov. 2005. [Online]. Available: https://www.congress.gov/crs-product/RL33141

[60] J. L. Beven, L. A. Avila, E. S. Blake, D. P. Brown, J. L. Franklin, R. D. Knabb, and *et al.*, "Atlantic hurricane season of 2005," *Mon. Weather Rev.*, vol. 136, no. 3, Mar. 01, 2008.

[61] T. Wachtendorf, B. Brown, and J. Holguin-Veras, "Catastrophe characteristics and their impact on critical supply chains: problematizing material convergence and management following hurricane katrina," *Journal of Homeland Security and Emergency Management*, vol. 10, no. 2, 2013. [Online]. Available: https://doi.org/10.1515/jhsem-2012-0069

[62] S. Crow, "Katrina: Lessons learned," *Sheriff*, vol. 60, no. 2, p. 34, 2008.

[63] R. L. Peck, "Katrina's lesson," *Nurs. Homes*, vol. 54, no. 11, p. 6, 2005. [Online]. Available: https://www.thefreelibrary.com/Katrina%27s+lesson.-a0140146415

[64] U. S. G. S. (USGS), "What is a landslide and what causes one?" 2021. [Online]. Available: https://www.usgs.gov/faqs/what-a-landslide-and-what-causes-one?qt-news_science_products=0#qt-news_science_products

[65] D. N. de Planeación, "Conpes 3904," 2017. [Online]. Available: https://colaboracion.dnp.gov.co/CDT/Conpes/Económicos/3904.pdf

[66] D. Cheng, Y. Cui, F. Su, Y. Jia, and C. E. Choi, "The characteristics of the mocoa compound disaster event, colombia," *Landslides*, vol. 15, no. 6, 2018. [Online]. Available: https://doi.org/10.1007/s10346-018-0969-1

[67] A. Siddiqi, K. Peters, and J. Zulver, "'doble afectación': living with disasters and conflict in colombia," 2019. [Online]. Available: https://doi.org/10.17863/CAM.50182

[68] D. M. Rodriguez-Coca, J. A. Espejo-Díaz, and W. J. Guerrero, "Análisis de los desastres de armero 1985 y mocoa 2017 en colombia utilizando el modelo pressure and release," in *Investigaciones en gestión del riesgo de desastres para Colombia: contribuciones locales, regionales y nacionales 2023*, 2023, pp. 191–208.

[69] J. A. Espejo-Díaz and W. J. Guerrero, "A bi-objective model for the humanitarian aid distribution problem: Analyzing the trade-off between shortage and inventory at risk," in *Applied Computer Sciences in Engineering*. Springer International Publishing, 2019, pp. 752–763.

[70] U. C. Fund, "Colombia co: Mocoa avalanche humanitarian situation," 2017. [Online]. Available: https://tinyurl.com/3yjxktjw

[71] J. L. Wieczorek, G. F. Larsen, M. C. Eaton, L. S. Morgan, and B. A. Blair, "Debris-flow and flooding hazards associated with the december 1999 storm in coastal venezuela and strategies for mitigation," Geologic Hazards Team, Tech. Rep. 01-0144, 2002. [Online]. Available: https://pubs.usgs.gov/of/2001/ofr-01-0144/

[72] M. C. Larsen, G. F. Wieczorek, L. S. Eaton, and H. Torres-Sierra, "Natural hazards on alluvial fans: the debris flow and flash flood disaster of december 1999, vargas state, venezuela," in *Proceedings of the Sixth Caribbean Island Water Resources Congress*, Mayagez, Puerto Rico, 2001. [Online]. Available: http://pubs.er.usgs.gov/publication/70171329

[73] R. Altez, "Muertes bajo sospecha: Investigación sobre el número de fallecidos en el desastre del estado vargas, venezuela, en 1999," *Cuad. Med. Forense*, vol. 13, no. 50, Jan. 14, 2008. [Online]. Available: https://scielo.isciii.es/pdf/cmf/n50/art03.pdf

[74] J. L. López, "Una visión crítica sobre el desastre de vargas: ¿qué se ha hecho? ¿qué falta por hacer?" *Rev. la Fac. Ing. Univ. Cent. Venez.*, vol. 26, no. 3, pp. 63–81, 2011. [Online]. Available: http://saber.ucv.ve/ojs/index.php/rev_fiucv/article/view/15408

[75] J. Moreno-Murillo, R. Duque, and J. Ordoñez, "The recurrent debris flows in mocoa -colombia," in *E-Proceedings of the 38th IAHR World Congress*, 2019. [Online]. Available: https://www.researchgate.net/publication/336196760_THE_RECURRENT_DEBRIS_FLOWS_IN_MOCOA_-COLOMBIA

[76] E. B. Guédez, "La desigual vulnerabilidad de las poblaciones ante catástrofes naturales: el caso del desastre de vargas (venezuela) en 19991," *Encrucijadas. Rev. Crítica Ciencias Soc.*,

no. 8, 2014. [Online]. Available: https://dialnet.unirioja.es/servlet/articulo?codigo=4999322

[77] P. V. Lezama, *El poder y la catástrofe. Venezuela bajo la tragedia de 1999*. Taurus, Santillana, 2010. [Online]. Available: https://www.researchgate.net/publication/298809965_Poder_y_catastrofe_Venezuela_bajo_la_Tragedia_de_1999

[78] R. A. Harrington. (2020) Case fatality rate. [Online]. Available: https://www.britannica.com/science/case-fatality-rate

[79] T. Manichi. (2016) 2.4 trillion yen in fukushima crisis compensation costs to be tacked onto power bills. [Online]. Available: https://mainichi.jp/english/articles/20161210/p2a/00m/0na/002000c

[80] C. Genatios and M. Lafuente, "Lluvias torrenciales en vargas, venezuela, en diciembre de 1999: Protección ambiental y recuperación urbana," *Boletín Técnico*, vol. 41, no. 2–3, 2003. [Online]. Available: https://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0376-723X2003000200004

[81] E. L. Quarantelli, "Converting disaster scholarship into effective disaster planning and managing: Possibilities and limitations," *Int. J. Mass Emerg. Disasters*, vol. 11, no. 1, pp. 15–39, 1993. [Online]. Available: https://doi.org/10.1177/028072709301100102

[82] K. Moriyama, D. Sasaki, and Y. Ono, "Comparison of global databases for disaster loss and damage data," *J. Disaster Res.*, vol. 13, no. 6, 2018. [Online]. Available: https://doi.org/10.20965/jdr.2018.p1007

[83] T. Betten, K. V. Pettersen, and E. Albrechtsen, "Learning in municipalities after disasters," *Disaster Prev. Manag. An Int. J.*, vol. 30, no. 3, 2021. [Online]. Available: https://doi.org/10.1108/DPM-04-2020-0092

[84] G. Paulsen and J. Cangelosi, "Disaster planning," *Outlook*, vol. 61, no. 4, 1994.