

The Impact of Hurricane Maria on Individuals Living with Non-Communicable Disease in Puerto Rico: The experience of 10 communities

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Abstract

Background

Coinciding with the rising non-communicable disease (NCD) prevalence worldwide is the increasing frequency and severity of natural hazards. Protecting populations with NCDs against natural hazards is ever more pressing given their increased risk of morbidity and mortality in disaster contexts.

Methods

This investigation examined Hurricane Maria's impact across 10 communities in Puerto Rico to determine whether and how disaster impact and community attributes affected NCD management. We conducted 40 qualitative interviews with mayors, first responders, faith leaders, community leaders, and municipal employees, with 4 interviews per selected municipality. Using QSR NVivo software, we coded interview transcripts and created categorical community-level impact variables based on participant responses. We undertook thematic analysis to characterize community-level impact and consequences for NCD management, and to identify convergent and divergent themes. Using a matrix coding query, we compared NCD management experiences across communities by impact variables and community attributes.

Results

The delivery of healthcare, pharmacy, and dialysis services was compromised due to facility structural damage and ineffective contingencies for electrical power and water supply. The challenges resulting from power outages were immediate, and individuals who were reliant on life-sustaining medical equipment, dialysis, or the refrigeration of medications were most vulnerable. Inaccessible roadways and the need to travel greater distances to locate operational health services were major impediments to transporting patients in need of NCD care, with those requiring dialysis and living in remote, mountainous communities at highest risk due to landslides and lengthy roadway obstruction. These barriers were compounded by limited communication to locate services and coordinate care. Two weeks post-hurricane, emerging challenges to NCD management included widespread diesel fuel shortages for generators, and shortages in medications, oxygen, and medical supplies. In the weeks to months post-hurricane, the emergence or exacerbation of mental health disorders was characterized as a pressing health concern.

Conclusions

Study findings identify contributors to morbidity and mortality among individuals with NCDs following Hurricane Maria. The degree to which these impacts were experienced across communities with different characteristics is discussed, offering important lessons regarding the impact of catastrophic disasters on NCD management for improve community disaster resilience.

Background

In the aftermath of disasters from natural hazards, the disproportionate risk of morbidity and mortality for populations with non-communicable diseases (NCDs) is not a new phenomenon. This disparity has been evident following numerous disasters in recent U.S. history, including Hurricanes Charley, Frances, Ivan, and Jeanne in 2004, Katrina in 2005, Sandy in 2012, Irma, Maria, and Harvey in 2017, the west coast wildfires of 2017, 2018, and 2000, the COVID-19 pandemic beginning in 2020, and the Texas winter storm in 2021, to name a few (1–13). While Hurricane Katrina in 2005 stimulated efforts to better address the needs of individuals with underlying NCDs in disasters, policies, guidelines, and disaster preparedness frameworks have not kept stride with the notable demographic and epidemiological shifts seen in the U.S. population since the mid-2000s (14–21). NCD prevalence and risk factors are on the rise in the U.S. and worldwide (22–24), and NCD risks and management are determined by an individual's socioeconomic status (SES) (25). With a rapidly aging population (26–28), Puerto Rico has a particularly high prevalence of numerous NCDs, including diabetes (16.7%), obesity (32.8%), asthma (18.1%), cardiovascular disease (7.2%), depression (17.9%), and chronic kidney disease (31.6%) (29,30). Coinciding with these trends, and compounding risk for individuals with NCDs, are the increasing frequency and severity of natural hazards (31–35) combined with the aging infrastructure of communities across the U.S. (36–42). Given the trajectory of these demographic, epidemiological and climatological trends, protecting populations with NCDs against natural hazards is ever more pressing (14,15,43–48).

In disaster contexts, populations with NCDs tend to be at greater risk of excess morbidity and mortality due to the exacerbation of their conditions, worsening of contextual conditions, disruptions to their treatments or required diets, inability to operate medical devices, and difficulty accessing prescription medications (10,16,45,47,49–62). Victims of large-scale, catastrophic natural disasters that destroy infrastructure, health facilities, and telecommunications are at even greater risk; yet there has been little research to understand the impacts of disasters of this magnitude on individuals with NCDs (2,4,5,47,50,63–65). A limited number of studies have shown that individuals with NCDs, including chronic kidney disease, diabetes, and mental health disorders, were severely affected following the 2017 Hurricane Maria in Puerto Rico (44,66–72), and one study has estimated that the leading causes of death after Hurricane Maria were due to complications from NCDs such as diabetes, cardiovascular disease, and Alzheimer's (66). However, incomplete death certification data limit assertions in this regard (73). Furthermore, Hurricane Maria, which devastated Puerto Rico by causing major damage to infrastructure, flooding, landslides, extended electrical and telecommunications outages, and disruption to health services delivery (52,74–78), was also followed by a lengthy and problematic recovery (79–82). It is probable that this difficult recovery contributed to excess morbidity and mortality among people living in Puerto Rico; while there is a study currently underway (83), there are otherwise no studies that have explored how this widespread destruction and delayed recovery affected the

management and treatment of NCDs. Gaining a better understanding of how these factors affect the management and treatment of NCDs can aid in more comprehensive and community-oriented disaster preparedness efforts.

Our research team from the [UNIVERSITY] estimated an excess mortality of 2,975 from Hurricane Maria between September 2017 and February 2018 (84,85), with older adults and residents of municipalities with lower SES at elevated risk of death for longer during that time period (84,86). Preliminary results from this study and one other study suggest that individuals with NCDs may have been particularly affected by the hurricane's impacts (66,86). Based on these initial findings, this investigation sought to characterize Hurricane Maria's impact across ten communities in Puerto Rico with varying characteristics to understand community-level attributes and impact factors that may have contributed to disproportionate morbidity and mortality among individuals with NCDs. The experiences from this event offer important lessons regarding the impact of catastrophic disasters on NCD treatment and management, and these experiences must be understood to improve community and health system resilience and preparedness for future disasters.

Methods

Approach. For this investigation, we used a case study approach (87) and grounded theory methodology (88) to conceptualize disaster impact based on diverse stakeholder perspectives from affected communities, to identify populations that were most vulnerable to the hurricane's impacts, and to understand how these impacts affected the health and well-being of these populations beyond the immediate disaster response period. The rationale underlying an examination of disaster impact is conceptually rooted in the potential influence that impact type (e.g., flooding vs. landslides) (89), sequelae (health service closure vs. roadway blockage) (90), magnitude, and duration of effects have on determining health outcomes following disasters. Furthermore, our preliminary research suggested that the hurricane disproportionately affected individuals with NCDs (85,86), and municipalities with lower SES (84). Consequently, this study examined similarities and differences in hurricane impact across 10 cases of lower SES communities (the term 'community' will be used interchangeably with 'municipality') with varying attributes in terms of geographic location, terrain, and baseline access to health services to determine whether and how these variations in disaster impact and community attributes affected chronic disease management post-hurricane.

Participant Selection and Recruitment. In order to construct a participant selection frame, we created a municipal database of categorical community attribute variables based on data sources found in Table 1.

Table 1
Community Attribute Variables and Data Sources

Categorical Variables	Values	Data Source(s)
Region	Northern (N), Southern (S), Eastern (E), Western (W), Central (C)	Regional Map (88)
Terrain	Coastal, inland/mountainous	Topographic map (89)
Socioeconomic index (SEI)	Very Low SEI (39.0–47.5) Low SEI (47.5–50.6) Moderate SEI (50.6–55.1) High SEI (55.1–59.2) Very High SEI (59.2–82.5)	Índice de Desarrollo Socioeconómico Municipal (90)
Change in death rate post-hurricane (%)	Decrease (-38.6-0) Very Minimal Increase (0–9.0) Minimal Increase (9.1–15.0) Moderate Increase (15.1–20.0) Severe Increase (20.1–28.3) Very Severe Increase (28.4–77.9)	Santos-Burgoa et al., 2018 (81); Instituto de Estadísticas de Puerto Rico (91); Meléndez & Hinojosa (92); U.S. Census Bureau (93)
Change in pop. density post-hurricane (%)	Very Minimal Decrease (-2.0- -12.0) Minimal Decrease (-12.1- -16.0) Moderate Decrease (-16.1- -22.6) Severe Decrease (-22.7- -36.0) Very Severe Decrease (-36.1- -275.1)	Santos-Burgoa et al., 2018 (81); Instituto de Estadísticas de Puerto Rico (91); Meléndez & Hinojosa (92); U.S. Census Bureau (93)
Hospital Access (min.) <i>(Calculated average travel time in minutes to nearest hospital)</i>	Very High Access (7.5–15.2) High Access (15.2–21.5) Moderate Access (21.6–28.7) Low Access (28.7–37.0) Very Low Access (37.1–61.1)	open street map (94); DHS geocoded hospital dataset (95); population density (96)
Dialysis Access (min.) <i>(Calculated average travel time in minutes to nearest dialysis facility)</i>	Very High Access (9.7–15.7) High Access (15.8–20.3) Moderate Access (20.4–27.0) Low Access (27.1–38.0) Very Low Access (38.1–77.0)	open street map (94); CMS dialysis facility database (97); population density (96)

All municipalities included in the selection frame had low or very low SES (91). Some variables pertained to community attributes that we anticipated would influence the type of hurricane impact experienced (e.g., coastal vs. mountainous terrain, or geographic location), while other variables we anticipated would potentially influence a community's ability to respond to health needs post-hurricane (i.e., baseline access to hospital or dialysis facilities). Two variables – change in death rate and change in population density from pre- to post-hurricane (a proxy for emigration) – were based on multiple data sources and our teams' prior analyses. The purpose of creating this frame was to enable purposive selection of 10 communities that was balanced in terms of regional representation, terrain, and baseline healthcare access, and would likely be diverse in terms of post-hurricane experiences (in order to protect participant privacy, the exact selected municipalities are obscured, and instead, the general geographical location of selected communities are indicated with circles in Fig. 1). One exclusion criteria was prior participation of the municipality in our initial 2018 research study (85).

We sought to conduct in-depth, semi-structured qualitative interviews with 4 individuals per selected community across stakeholder groups established in our prior research (85). These stakeholder groups were identified based on their knowledge of the hurricane's broader community impacts due to their role in disaster preparedness, response, or community support. Study participants were recruited by initially contacting the municipal mayor's office to introduce the study and request an interview with the mayor. Additional participants were identified through referral by the mayor or other respondents. Interviews were scheduled by phone to take place in the local community in a private location.

Data Collection. We conducted a total of 40 qualitative interviews in 10 (of 78) different Puerto Rican municipalities with varying characteristics (See Table 2 for community attributes), with approximately 4 interviews per community. Participants were recruited from the following stakeholder categories: mayors (n = 9); first responders (n = 9); faith leaders (n = 5); community leaders (n = 9); and municipal employees (n = 8).

Table 2
Community Baseline and Impact Attributes

Baseline Community Attributes					Impact Attributes		
Community	Region	Terrain	SES	Hospital Access (baseline)	Dialysis Access (baseline)	Death Rate Increase (post-Maria)	Pop. Density Change (post-Maria)
1	C	inland	Very low	Very low	Moderate	Very minimal	High
2	C	inland	Low	Very low	Very low	Very high	Very low
3	S	coastal	Very low	Moderate	Moderate	None	Moderate
4	S	coastal	Very low	Low	Low	High	Moderate
5	E	coastal	Very low	Low	Low	Minimal	High
6	N	coastal	Very low	Very high	Very High	High	High
7	N	coastal	Low	Moderate	Moderate	Very minimal	Low
8	C	inland	Low	Low	Very low	None	Moderate
9	C	inland	Low	Moderate	Moderate	High	Low
10	C	inland	Low	Very high	Very low	High	High

A semi-structured interview guide was developed to inquire about participant preparedness experiences as well as experiences during the response and recovery periods up to 6 months post-hurricane. Participants were asked about disaster communication and messaging, planning and decision-making processes, coordination efforts, and community engagement and collective actions during each of the preparedness, response, and recovery phases. Participants also characterized the hurricane's impact on their community, including consequences ranging from the duration of power outages (92) to impacts on resident morbidity and mortality. Additionally, participants were asked to identify the biggest threats to health and safety and the most vulnerable populations, as well as to self-rate their community's resilience and identify strategies that most contributed to resilience (results related to resilience reported elsewhere). The interview guide was translated into Spanish adequate to Puerto Rico and pilot tested with one participant from our prior study. Interviews lasted approximately one hour each, and were conducted over a 17-day period in November of 2019 by a three-person bilingual research team with substantial qualitative research experience. Interviews were conducted in private locations in municipal buildings, community centers, or places of worship. All participants provided informed consent, and all research protocols were approved by the [UNIVERSITY] Institutional Review Board. All interviews were audio recorded and transcribed in Spanish.

Data Coding and Analysis. A codebook was created according to a priori areas of inquiry. Spanish language transcripts were uploaded to QSR NVivo qualitative data analysis software and organized into cases by community. Each of 10 cases was assigned corresponding attribute values, and interviews were labeled by participant stakeholder groups (See Table 2). The first 5 interviews were double-coded, with resultant coding compared to ensure concordance or identify needed code book modifications by combining, adding, or removing codes. The remaining 35 interview transcripts were coded by a primary coder and then all coding was reviewed by a secondary coder, after which any discrepancies were discussed and resolved. During the coding process, based on participant responses, we constructed categorical variables at the case (community) level by averaging responses related to characterization of hurricane impact, including lengths of outages for electricity, water, telephone, and internet (See Table 3). These respondent-driven impact attribute variables were constructed to facilitate cross-case comparisons regarding disaster impact and consequences for populations with NCDs.

Table 3
Participant-Reported Community-level Hurricane Impact

Community	Electricity Outage	Water Outage	Telephone Outage	Internet Outage
1	> 6 months	> 3 months	> 6 months	> 6 months
2	> 6 months	> 3 months	> 6 months	Less than 6 mo.
3	Less than 6 mo.	> 3 months	Less than 6 mo.	> 6 months
4	Less than 6 mo.	> 3 months	> 6 months	> 6 months
5	> 6 months	Less than 3 mo.	Less than 6 mo.	> 6 months
6	> 6 months	Less than 3 mo.	> 6 months	> 6 months
7	> 6 months	> 3 months	Less than 6 mo.	Less than 6 mo.
8	> 6 months	Less than 3 mo.	Less than 6 mo.	> 6 months
9	Less than 6 mo.	Less than 3 mo.	Less than 6 mo.	Less than 6 mo.
10	> 6 months	Less than 3 mo.	Less than 6 mo.	n/r

Following the coding process, we undertook variable-specific analysis. Output by code was produced and reviewed to identify topics related to community-level impact and consequences for populations with NCDs, and to identify both common and divergent themes across cases during the pre-hurricane, response, and recovery periods. We then conducted a more targeted cross-case analysis using a matrix coding query. We compared responses between

communities by impact factors (i.e., length of electrical outage, change in death rates and population density from pre- to post-hurricane) and community attributes (i.e., terrain, hospital access, dialysis access). We sought to determine whether the experiences of individuals with NCDs varied by these impact variables and community attributes.

We created a matrix with a summary of results related to impact experiences (type of impact, such as flooding or landslides; length of impacts, such as road closures, power outages) and populations described as being most vulnerable. Results were organized by community and time period (response and recovery phases). Following a review of the matrix results summaries across cases, we further thematically organized results by participant-reported impacts related to NCDs. Findings from the comparative analysis were summarized, and illustrative transcript segments were identified and translated to English.

Results

Hurricane Maria's Impact on Healthcare Service Delivery and NCD Management and Treatment. In the aftermath of Hurricane Maria, communities throughout Puerto Rico experienced considerable challenges to delivering healthcare and other services, which contributed to the emergence and/or exacerbation of NCDs. We include results related to the following NCD categories: diabetes, chronic kidney disease, cardiovascular disease, respiratory disease, and mental health disorders, as well as results for unspecified health conditions that require continual care. Results from key informant interviews are presented in 6 thematic areas: 1) Compromised healthcare facilities that impeded service availability; 2) Inadequate resources for healthcare facility operation; 3) Difficulty accessing healthcare services due to roadway obstruction and flooding; 4) Prescription medication and medical supply shortages; 5) Inoperability of medical equipment; and 6) Mental health disorder emergence or exacerbation. Results are presented by theme, and cross-cutting findings related to hurricane impacts, such as widespread electrical outages, diesel fuel shortages, and interruptions to potable water supply, are discussed below by theme where relevant. For each major theme, participant responses that detail how those factors contributed to fatalities are also included.

Theme 1: Compromised Healthcare Facilities - The delivery of healthcare and pharmacy services was compromised due to structural damages to facilities.

The types of facilities that were reported as sustaining damage so as to compromise health service delivery included hospitals (Communities 6, 8, 9), clinics (Communities 1, 5, 7, 8), medical offices (Communities 3, 10), laboratories (Community 3), dialysis treatment centers (Community 1), and pharmacies (Communities 3, 5, 10). Communities with varying levels of baseline access to hospitals or dialysis centers, even including municipalities with moderate to very high access, reported experiencing compromised healthcare services due to healthcare facility damage, especially among coastal municipalities (Communities 5–7). In two coastal communities, damage to roofs of hospitals in particular resulted in the decision to limit the scope of services and hours of operation (Communities 5, 6).

I witnessed the physical damages to the structure of the hospital. There were areas where the roof fell apart... we started to see how a part of the hospital was collapsing, all of that... we could operate the hospital, but operating it, I mean, in conditions that were not ok for it to be open. Even though the physical infrastructure wasn't all ok, I had doctors, nurses, we could serve the population...other hospitals had collapsed entirely.

- Mayor, Community #5

The disruption of services was unavoidable. The hospital suffered damages. At one point after the hurricane, we thought the hospital would have to be completely evacuated due to damage on the roof that flooded the emergency room, intensive care...

- Emergency management personnel, Community #6

In other communities, pharmacy and laboratory services had to be temporarily suspended or offices closed entirely due to the damage (Communities 1, 3, 5, 7, 9, 10).

The pharmacy was non-operational for many weeks. - Municipal employee, Community #10

We lost pharmacies... we lost laboratories, we lost medical offices, the impact was so great for our people. - Mayor, Community #3

Theme 2: Lack of contingencies for electrical power and water supply interruptions presented barriers to providing healthcare services.

Widespread electrical outages were a major barrier to healthcare service delivery. Eight (8) communities described the lack of electricity as one of the most important barriers to providing healthcare and pharmacy services post-hurricane (Communities 1, 3, 5–10). Power outages contributed to the closing of facilities that did not have contingencies in place to restore this resource.

Well, for me the biggest threat was access to medical services. Doctors' offices were closed, pharmacies were closed, because there was no way to operate them, there's no electricity... - Municipal employee, Community #10

...they were sick and where were they going to go? Then, the clinics were the closest thing, but there was no electricity. There was nothing. We were not prepared.

- Faith leader, Community #7

Seven of the 10 selected communities reported being without electricity for more than 6 months on average (Communities 1–2, 5–9), while 3 communities reported less than a 6-month average of electrical outages in their municipality (Communities 3, 4, 10). Participants across municipalities also noted considerable variability in the length of outages between urban and rural areas, with more remote areas typically experiencing more delays in restoring service.

Electricity took longer. In my case, it was restored eight months later. And, to this day, there are still places with no electricity [2 years]. - Faith leader, Community #7

There were places here that went the entire year. For example, where I live, we had 42 days without electricity, I would say on average 4–5 months. - Mayor, Community #1

Six out of the 7 communities with electrical outages lasting more than 6 months mentioned the lack of electricity (in general) as one of the biggest threats to health and safety post-hurricane. Only 1 community with a shorter duration of electrical outage mentioned the outages as one of the biggest threats due to disparities in the length of electrical outages between urban and rural areas. Study participants from communities that had lower access to hospitals at baseline combined with longer periods of electrical outages were more likely to identify the inability to provide health care due to the lack of electricity as one of the biggest threats to health and safety (Communities 1, 5, 8). Despite having longer electrical outages, communities that had moderate to high access to hospitals at baseline did not list this as one of the biggest threats (Communities 6, 7, 9).

There were many people that had many health conditions that required some medical equipment. If preparations weren't made to provide electricity for that equipment, they were affected. - Municipal employee, Community #8

...sick people at home the need electricity to be able to keep people alive...it became somewhat difficult, they had to find generators for those people, electrical generators. Many times in the hospital they had to provide them with diesel and generators so they could keep working. It was not easy. It was very difficult 3 or 4 months after the hurricane. – Mayor, Community #1

Injured people, people with respiratory issues because of electricity, that not everyone had a generator at that moment, many people that have those conditions.

- *Emergency management personnel, Community #5*

Sick people at home that needed electricity to keep people alive because they needed electricity, well it turned to be quite difficult, generators had to be given to those people, electric generators, many times hospitals had to be provided with diesel and generators so they could continue to operate, it wasn't very easy it was very difficult in the first 3 or 4 months after the hurricane. - Mayor, Community #1

The bedbound were affected because they did not have electricity, and if they did not have services, people who were given dialysis were the most affected.

– Community leader, Community #5

Unreliability of electrical contingencies was an immediate challenge to healthcare service delivery post-hurricane, while diesel fuel shortages became a challenge after approximately 2 weeks.

Three communities identified barriers to providing patient care due to problems with backup electrical generators for health facilities. These problems ranged from generator failures immediately post-hurricane (Community 9) to sporadic/periodic health facility closures due to generator failures (Community 8). In the case of one mountainous community, restoration of a failed hospital generator did not occur until almost one-week post-hurricane:

There was no communication with the hospital, the administration, until five days later, they notified us that the generator failed and there was no way to operate... The hospital was open the night of the hurricane, but after the hurricane passed, the hospital was closed. When I approached the hospital, they told me the generator failed. They had to close the hospital and [the municipality] was without a hospital for 6 days and everyone had to go to [another town] to tend to any emergencies. It was very tough.

- *Mayor, Community #9*

Another municipality described the inability to power the local clinic for 24-hour service delivery due to the limited capacity of an old generator (Community 5)

In the clinic, we had a generator, which was an old generator, that we gave maintenance to be able to keep it operational...we were operating with a limited schedule. We couldn't have the generator 24 hours because it was going to break on me. And I asked the people from FEMA to please find me another generator to be able to have the clinic working 24 hours, and it arrived 84 days after the hurricane. - Mayor, Community #5

Respondents from all 10 communities also described diesel fuel shortages that began a couple weeks post-hurricane, which introduced another impediment to patient care since electrical generators that sustained the operation of water pumps and powering hospitals, clinics, pharmacies, and other health-related facilities and businesses required diesel fuel. Consequently, diesel shortages, whether temporary or persistent, had an impact on the operational status of medical facilities, especially in more remote, inland municipalities (Communities 1, 8, 10).

The first two weeks, the two clinics we had in the area were in operation, but once they ran out of gasoline... they closed, we had to go to another town...some 35 minutes to go to that secondary hospital facility where they were accepting [patients].

- *Emergency management personnel, Community #1*

Water outages compromised healthcare service delivery and dialysis treatment. Additionally, 3 communities mentioned the lack of electricity as a barrier to water supply delivery (Communities 5, 7, 9), indirectly affecting healthcare service delivery and home-based care for health conditions. A total of 5

communities reported being without tap water for more than 3 months on average (Communities 1–4, 7), while 5 communities reported less than 3 months of tap water outages (Communities 5, 6, 8, 9, 10), with substantial variability between urban and rural areas in any given community.

There were sectors that always had water, it would be cut off per hour when the water pump ran out of diesel but there were sectors that went 2 to 3 weeks without water... the more isolated sectors. - Emergency management personnel, Community #3

It depends on the sector because there are multiple neighborhoods. Anything closer to the urban center, by November there was electricity and water... It was maintained, in the town, here in the center, but for other sectors that depended on electricity for water pump systems...well, basically until February [2018]. – Faith leader, Community #6

My last community got electricity within 7 months and the first by December.

- Mayor, Community #7

In the urban area... that includes the hospital and government offices, we were without water for about one week, but the population... the rural areas, I would say three months. - Mayor, Community #8

One community described shortages in the bottled water supply, which required rationing of this resource (Community 6).

The little water that arrived, I remember like it was today, the mayor said we had to share because there were more than 50 thousand inhabitants, we have to share this water. And we went to houses with small bags and some water bottles to give a little to everyone. And people did not understand. They thought we were hiding them. And no, there was so little water that we could only give out 12 water bottles to give some to everyone. And that broke our hearts. - Community leader, Community #6

Another municipality described the challenges that interruptions to the water supply created for the nearby dialysis center (Community 1).

We also had a situation here: the dialysis center had a processing plant, a plant where... a water treatment plant, but they ran out of water, we had to bring water to them.

- Emergency management personnel, Community #1

Given the inadequacy of resources to operate healthcare facilities, many closures led patients to travel to other communities in search of care when roadways were cleared, thus shifting patterns of service utilization. One community discussed how patients had been diverted to their dialysis center due to closures of other locations, and accommodating the increased patient load strained the center's resources (Community 1).

In this region it was the only one, and patients were coming from other towns...so they started treating [the additional] people...to meet the demand. - Emergency management personnel, Community #1

Mortality related to compromised health services or facilities. These limitations in the availability of healthcare services were reported to compromise quality of care for patients (Community 6), and were cited as contributors to deaths of patients with NCDs, including cases where patients died in hospital parking lots or police stations due to respiratory conditions, or died in route to an alternative health facility or emergency medical care (Communities 2, 5, 8, 9).

I saw people die in the clinic parking lot... I had already closed the clinic. Family members took her because she could not breathe, but it was closed. They got an ambulance to see if they could take her somewhere else but, on the way, [her vital signs] crashed, [she] died... It's something that I'll have with me for the rest of my life, to see a person that arrives dead to the clinic, to see a friend, well not see her, but hear that she died the next day because there wasn't a hospital open... these are things that you say: it is very painful to see that those things were happening. - Mayor, Community #5

For me it was very painful that they died due to...as the days went on, they could not get the services they needed. – Faith leader, Community #6

I do know people who were ill and their treatments were delayed, people who had to leave the country to continue their medical treatments... many people for whom the process was accelerated and they died earlier than they would have.

- Mayor, Community #3

Theme 3: Inaccessible roadways and the need to travel greater distances to locate operational healthcare services were major impediments to transporting patients to needed care, especially for NCDs. These barriers were compounded by limited communication to locate available services and coordinate care.

According to study participants, difficulties accessing healthcare services for the management of NCDs were due to blocked roadways from debris, landslides, flooding, and collapsed bridges; the lack of transportation/medical transport; and limited communication to coordinate care. Two communities with low hospital access at baseline (Communities 5, 8) perceived limited or unavailable health services as one of the biggest threats to health and well-being post-hurricane, while only one community with moderate hospital access identified this as one of the biggest threats (Community 3).

Blocked Roadways. Communities with both high and low access to hospitals and dialysis facilities at baseline mentioned difficulties getting to healthcare services post-hurricane due to impassable roadways from debris, flooding, and landslides (Communities 1–3, 5, 6). While blockages from debris were reported in all communities, flooding was more commonly reported by coastal municipalities (Communities 3, 4, 6, 7), and took approximately 7–14 days to clear, with town centers being cleared earlier and outlying neighborhoods cleared later.

As a matter of fact, [our municipality] was [in the top 10] most affected on the Island because some communities had flooding of more than 10 feet, those are communities that are very close to [the river]... - Mayor, Community #6

Within a week and a half and 2 weeks, they were still clearing roads to reach the countryside. Within 7–8 days the urban sector was cleared. - Emergency management personnel, Community #3

While roadways often took longer to clear, some communities prioritized the accelerated clearing of roads to facilitate patient transport:

We, I think in record time, one day, at most a day and a half, we had cleared the highways. The main roads were my priority so that if someone was sick, they could go to the hospital and receive care. - Mayor, Community #5

Landslides were more commonly reported by inland municipalities with mountainous terrain (Communities 1, 2, 8–10), contributing to longer road blockages, sometimes lasting up to 3 weeks or longer (Communities 1, 2, 8).

Well, in general all roads were obstructed. There were situations where more than a mile of [one] route had collapsed. You got there and you would say it was the end of the road, all the cliffs there, trees in the middle of the road...the first two weeks we were clearing small pathways. There was a [another] route that was closed for about a month. They kept it closed because the road had collapsed. People had alternate routes, they were not isolated because there were alternate routes they could take to go around and get to town. Everything started flowing faster after the first month. -Emergency management, Community #2

There were no passable roads...by the third week, a month...almost all roads had been opened. - Community leader, Community #2

Well, there was a road we spent 22 days digging out dirt because it was a long road and everything collapsed over that road. We spent 22 days with heavy machinery clearing that road. Around 2,000 homes were affected, of which 700 were completely lost. I had a case of a large road that fell and that road went around and under these houses, a giant rock took with it homes with vehicles and animals inside, they fell into the river and disappeared. - Mayor, Community #1

We had the neighborhood...we spent two weeks without being able to access that community. In another neighborhood, around two weeks as well to get to that community...but we had to do it with 4x4 vehicles, using alternate routes and back roads to get to those people and get them supplies. – Police officer, Community #8

Blocked roads were specifically mentioned as critical barriers to accessing healthcare for individuals with NCDs who needed regular services and treatments for management of their health conditions (Communities 3, 5, 6, 10).

Diabetics, those with heart conditions, those with high blood pressure. Those that could not go to hospital when they needed to due to factors we know, in terms of the blockages that there were... - Mayor, Community #6

Yes, here it wasn't diseases, rather people that were sick in their homes and could not get treatment because they could not go out. Yes, I know a person in [one] neighborhood that was sick and could not be taken to a hospital, but he was very sick but not because he acquired a... rather because he was sick and could not go out...

- *Municipal employee, Community #10*

It was an older man, 90 years old, they had him in a room without an air conditioner, without electricity, nothing. When I saw him, I thought it was a sock he had on, but it was not a sock, he had a gangrenous leg. The leg was, black, black, black.

- *Mayor, Community #5*

Dialysis Treatment Inaccessibility. Accessing dialysis treatment post-hurricane for patients with chronic kidney disease was of particular concern for study respondents, and a total of 7 out of the 10 selected communities mentioned dialysis treatment interruption as one of the biggest threats to health post-hurricane. Among those communities, 2 had very low access (Communities 2, 8, 10) and 2 had low access (Communities 4, 5) to dialysis at baseline, while 2 had moderate access (Communities 1, 3). Five communities (Communities 2, 4, 5, 8, 10) specifically mentioned dialysis access barriers related to road blockages and transportation for patients who needed to travel farther distances to find open centers.

Others could not get their dialysis on time, others that could not... I mean... Even though it wasn't that the night of the hurricane the wind impacted them or they drowned or something like that, but yes, related to the hurricane itself, many lost their lives. They didn't have service, necessary care, and well, couldn't hold on. - Municipal employee, Community #10

There were people that came here after 3–4 days because they could not receive dialysis, people that needed dialysis but because they were stuck, they came here.

- *Emergency management personnel, Community #2*

Telecommunications Outages. Furthermore, telecommunication service outages compounded challenges to accessing healthcare services for patients with NCDs. This barrier made it difficult for emergency managers, emergency medical personnel, and patients to communicate with each other to assess needs, coordinate care for individuals who lived remotely or had persistent roadway blockages from the storm (Communities 1, 2), request medical transport, and call ahead to verify whether services were operational in neighboring communities (Community 3).

There was a situation with a patient where we had to find alternatives to reach them, to communicate because by that time, communications were a little better in terms of radio, not cellphones. That community was totally unreachable for communication...

- *Emergency management personnel, Community #1*

There was no way of getting to the hospital, no way of going to Ponce because we didn't, the vehicles, the sea, there were many things that we were examining and it wasn't until we made the first trip and arrived in Ponce that we knew we could get there and verify whether they were going to receive patients or not. - Mayor, Community #3

Distance to Healthcare Services. Individuals living in areas located outside of town centers or at a greater distance from health facilities experienced compounded access barriers due to the travel distance required to access services in another community (if local services were non-operational), increased likelihood that roadways to leave their homes were still blocked, and challenges for medical transport to reach remote patients (Communities 1–3, 7). However, those living in more urban areas, but not on a main road, still experienced barriers since roadway clearing near their homes was also delayed (Communities 6, 7). Some study participants indicated that people in need of health services decided not to seek medical care due to challenges they faced traveling long distances and the perception that facility conditions or quality of care would be compromised (Communities 4, 5).

Because it was difficult to go to the hospitals – since the one in our community was not operating, one had to go to [other cities], then it was harder for people. Many times...because they did not have transportation, they stayed, and did not get treated. Therefore, the situation worsened in terms of physicians here. - Community leader, Community #5

Diesel Fuel Shortages for Emergency Medical Transport. In one community, diesel fuel shortages were discussed as a barrier to using emergency medical transport vehicles (Community 3).

An Emergency Medicine supervisor arrived saying that the government did not have diesel for their ambulances. He asked me for diesel. As an agency, of course, yes, the ambulances are for the services of my people. But when I called them asking for services, they could not provide any... then that bad decision of not giving me those services was what made diseases worsen and people needed medical assessments.

- *Emergency management personnel, Community #4*

Mortality from Health Service Inaccessibility. Interestingly, baseline level of hospital access did not necessarily translate to increased death rates post-hurricane – 3 communities had low (Communities 5, 8) or very low (Community 1) hospital access at baseline, but experienced no (Community 8), very minimal (Community 1), or minimal (Community 5) increases in death rate post-hurricane. Conversely, 3 communities had moderate (Community 9) or very high (Community 6, 10) access to a hospital at baseline, yet experienced a severe increase in post-hurricane death rates. According to respondents, delays in care for NCDs due to the inaccessibility of healthcare services were contributors to deaths regardless of baseline access.

They lacked some services, so they had to get to town. There was no way to get them back home after they got to town, and by the time the person had arrived, they could have worsened or died, sadly. - Community leader, Community #9

Five out of the 7 communities that described challenges in accessing dialysis for patients in the aftermath of the hurricane also reported deaths of dialysis patients in their community due to these delays in treatment (Communities 2, 4, 5, 8, 10). Two of these communities had severe increases in death rates post-hurricane (Community 4 with low, and Community 10, with very low access to dialysis at baseline) and one had a very severe increase in death rate (Community 2, with very low dialysis access at baseline).

As consequences of [the hurricane] because there are people who were getting dialysis and had to travel to other towns, there was no transportation, none. The area was not prepared to transport them and well, with the lack of medication and care, they died.

- *Firefighter, Community #2*

Yes, there were deaths. Delays in services caused many deaths. People that could not go to their appointments, people that, well, could not have their appointments, there was no electricity. There were many, not only deaths, but health complications.

- *Community leader, Community #4*

The lack of transportation for dialysis. I had people here that arrived without dialysis treatment for 8 days...People that were bedbound or had ulcers and had treatment, they were supposed to have air conditioning, an adequate temperature in their rooms, and didn't have them and that made the pain more acute. People with skin infections or some areas that did not receive medical treatment... there were more than 10 deaths because of the lack of medical transport. - Emergency management personnel, Community #4

For the 2 municipalities that experienced no increase (Community 8) or a minimal increase (Community 5) in death rates post-hurricane (both with either very low or low dialysis access at baseline), respondents still detailed substantial mortality among dialysis patients.

It was mainly dialysis. I had to escort people that needed dialysis or had delayed their dialysis. We had to escort them to the nearest hospital, transporting people who were already the color lilac. They've now died... they didn't pass away right after the hurricane - because their treatment was affected, eventually they died. Dialysis patients, I would say that here, totally related to Maria, over 100 cases. They were pretty high.

- *Mayor, Community #8*

They were affected because they were bedbound and because they did not have electricity. Since they didn't have electricity, people that received dialysis were the most affected. There were multiple deaths. There was no way of taking them to the doctor.

- *Community leader, Community #5*

Theme 4: Shortages of prescription medications, oxygen, and medical supplies presented major challenges to caring for people with NCDs.

Study respondents highlighted inadequate management of NCDs due to challenges accessing prescription medications, interruption to supplies of oxygen and other medical supplies, and difficulties refrigerating medications with electrical outages.

Prescription Medication and Medical Supply Shortages. All 10 selected communities, regardless of baseline access to hospitals or dialysis centers, mentioned shortages of prescription medications and medical supplies as major problems post-hurricane, especially for the management of NCDs, including diabetes, hypertension, cardiovascular disease, mental health disorders, and asthma. Furthermore, 4 communities identified prescription medication shortages as one of the biggest health threats post-hurricane (Communities 4, 6, 7, 10). Some respondents mentioned interruptions in the supply chain and transport of medications to local communities as major contributors, while others described pharmacy damage or closures as important factors in medication shortages.

Well, medications were not available, particularly for people with diabetes, insulin, for high blood pressure... - Mayor, Community #6

Then, a person's medication supply runs out, a hypertensive person, a cardiac patient, a diabetic person, a person, we're talking about, for me, in particular, maybe not for another person, but for me yes, the stress was a lot for a person that needed medication... and didn't have it accessible. Here, thank God, the hospital was able to operate without stopping. But whoever needed access to medications, there were difficulties here. - Municipal employee, Community #10

They ran out of medication... Then, well, she needed it, because she was older, and she needed that medication. We had to bring her to the hospital, through a narrow, bumpy path. But honestly, it was an odyssey, because of what happened that week after Hurricane Maria... medications were what people asked for the most.

- *Police officer, Community #8*

Electrical Outages as a Barrier to Medication Storage. Seven out of 10 selected communities identified the lack of electricity as a barrier to storing refrigerated medications, especially insulin for diabetes management (Communities 1–7). Among these 7 municipalities, 5 reported power outages lasting longer than 6 months on average, and while the other 2 communities regained electricity in the urban center relatively quickly, they still reported extended outages in rural areas, with some rural neighborhoods not regaining electricity until up to a year post-hurricane (Communities 3, 4).

You have people that have some treatment that's ongoing, that are diabetic, hypertensive... That don't have electricity, don't have a way to keep those medications refrigerated. - Mayor, Community #5

Since they didn't have electricity in their homes, when the insulin warmed up a lot, there was a lot of misunderstanding about insulin lasting, if it's not exposed to sunlight, for about 30 days. And people began to throw it away because they didn't have that information. That information was provided later, I heard. - Mayor, Community #3

People with diabetes, their insulin would be damaged since there was no electricity. It was very difficult to go and give them a bag of ice because, where could you get ice? Where there was electricity. And where was there electricity? Well, in the town they say there were generators, but in the country side it was not common to see a functioning generator... everyone prepared, yes - I have insulin for this much time...but no one knew how much time the need and suffering would go on. - Firefighter, Community #2

These six communities also described how diesel shortages created additional challenges for refrigerating medications, such as insulin (Communities 1–5, 7).

People who were bedbound and using refrigeration for medicine, those things, well there wasn't. Then there was no gasoline, you had to go look over there and the lines were very long and you would get there in the morning and still there was a line at night and when you reached the station, they would say "there's no more gasoline."

- *Community leader, Community #1*

Mortality Related to Prescription Medications. Six out of the 10 selected communities indicated that people had died in their communities due to a shortage of medications to treat NCDs, or the inability to refrigerate those medications to which they did have access (Communities 2, 5, 6, 8–10). Among these 6 communities, 5 reported having electrical outages lasting more than 6 months on average. Five of these communities indicated that deaths had occurred related to medication for diabetes (Communities 2, 5, 6, 8, 10), and 4 communities said deaths had occurred related to medication for hypertension (Communities 2, 5, 6, 10). Four of the 6 communities experienced severe (Communities 6, 9, 10) or very severe (Community 2) increases in mortality rates following the hurricane.

People didn't die in the hurricane, they died after the hurricane, for many reasons: lack of electricity, oxygen, medications. - Community leader, Community #9

Many elderly people, well, they died from their health conditions and there was no way to help them. There were elders that could not take their medications, you know, and they worsened, got sick, continued to be sick, and would even die. - Community leader, Community #6

And seeing whatever number of deaths, you realize that the majority of people died because of lack of medications. Couldn't get their dose, sugar levels went up, and boom! - Emergency management personnel, Community #6

Access to medications, that was fatal. In fact, I know people that shared their medications. - Faith leader, Community #7

Oxygen Supply Shortages. Six of the 10 selected communities reported shortages in oxygen supply (Communities 3, 4, 6, 8–10).

I remember we had to, at one point, run to get oxygen tanks, somehow find people that had oxygen tanks they were not using because... or people whose saturation started to drop in reality had their lives in danger and at risk of death, and we had to do a lot of arrangements, lots of things to get those things because the state was not providing them. - Mayor, Community #4

...I still get emotional remembering those moments (voice breaks) because of seeing people who needed oxygen... -Municipal employee, Community #10

Mortality Related to Oxygen Supply Shortages. All 6 of the communities reporting oxygen tank shortages indicated that deaths had occurred in their community because of these shortages.

In fact, people who were at the small hospital... many people died there as well because of a lack of oxygen, because sometimes if there weren't generators, they couldn't...

- *Municipal employee, Community #8*

We had a case of a person, the family had their grandmother at the house, she did not have oxygen at the house but she could walk. The bad thing was that she had asthma. She had a stabilizing treatment. Then, the hospital was closed. Well, they took her to the office, to the municipal police, they sat her down at the police station and when our paramedic went to assess her, she was dead, sitting right there in our reception area, in front of us. - Mayor, Community #8

Theme 5: Inoperability of medical equipment contributed to substantial morbidity and mortality among individuals who relied on electricity for the operation of this equipment.

Study participants identified individuals who relied on the use of medical equipment as a population that was particularly vulnerable post-hurricane, initially due to electrical outages, and later due to diesel fuel shortages to operate generators.

Electrical Outages as Barrier to Operating Medical Equipment. Eight out of 10 communities indicated that the extended outages of electricity contributed to inoperability of ventilators or other medical equipment for patients with NCDs and complex medical conditions (Communities 1, 3, 5–10). Six of these communities reported electrical outages lasting more than 6 months on average post-hurricane (Communities 1, 5–9), while 2 reported experiencing electrical outages of less than 6 months (Communities 3, 10). Four of the 6 communities with electrical outages lasting 6 months or longer identified the inability to power medical equipment, especially ventilators, as one of the biggest threats to health and safety (Communities 5, 6, 8, 9). One community with disparities in electrical outage length between urban and rural areas mentioned difficulty powering medical equipment as one of the biggest threats (Community 4).

Many people had some type of impediment, some kind of need... They would need some equipment, yes. I heard of many situations, where people did not have electricity, the generator wasn't working. I believe there were many people who lost their lives in those areas. Many people were in their homes, and they needed special equipment, and the equipment required electricity. Then, when there was no electricity, they turned to generators, and if the generators failed at any moment for X or Y reason, then...

- *Municipal employee, Community #10*

Like I said the situation around health, the majority of people that suffered here were those that needed some equipment, because of the electricity situation, people that were bedridden, that needed oxygen, care for ulcers, many people passed away here. Like I said, the majority of people that died had preexisting conditions that were aggravated by María. Directly the day of impact no, but as a consequence of the situation the hurricane left behind, many people worsened and consequently died. - Emergency management personnel, Community #5

One community mentioned the electrical generator inoperability for a refuge, introducing a major barrier to individuals who needed electrical supply to operate life-sustaining medical equipment (Community 6).

...factors related to electricity. On many occasions, considering that many people should have ventilators and faced with the fact that the shelters where they were located did not have a functioning generator, then, that limited on many occasions that service. - Mayor, Community #6

Diesel Fuel Shortages. Post-disaster, all 10 communities reported shortages in gasoline, which created challenges for powering medical equipment. According to participants, few gas stations were receiving supply, lines were long (Community 5), and strict rationing made it hard to obtain gasoline (Community 4). Furthermore, 3 municipalities described delays of 1 week (Community 8 due to blocked roadways), 10 days (Community 2 due to blocked roadways), and 1 month (Community 6) to receive diesel supply in their communities.

There was a lady with hypertension, her husband went out to look for gasoline for their generator, but the lines to look for a little container of gasoline took 3 hours. That man was in line to keep his generator on, and when he arrived at home after 2 hours in line, he found his wife on the floor because she had collapsed. By the time he brought her to the hospital, she was already dead. Many cases like that. - Mayor, Community #5

Here, the biggest problems were regarding gasoline. Some families had generators, but gasoline was difficult, because roads were obstructed for those first trucks, they got here after a week. That first week, fuel was critical. -Municipal employee, Community #8

For us, for fuel to be available in this area, we started seeing it around 10 days after because the road was split in half, we had to clean it so trucks could go up there.

- *Emergency management personnel, Community #2*

Residents living more remotely experienced additional challenges to obtaining gasoline since they had to use a substantial amount of gasoline just to arrive to the gas station, and described the additional complexity of balancing competing priorities with limited supply such as powering emergency medical transport vehicles, vehicles for supply delivery, and to power generators (Communities 1, 2, 8, 10).

Mortality related to inoperability of medical equipment. Among the 8 municipalities that mentioned difficulty operating ventilators or medical equipment due to a lack of electricity or gasoline for generators, all of them reported that this difficulty contributed to deaths in their community.

Many deaths happened not as a direct cause of the rain, winds, rather with the passage of time. There were many people, many families lost fathers, mothers, people that were bedbound. And how are you going to say that that wasn't... that it was only because of natural or medical circumstances, or that they were already sick? No, because a person that needs an oxygen machine in their home and they didn't have electricity, they were going to die because they needed the oxygen. - Faith Leader, Community #3

People who had respiratory conditions because they had to be connected to an oxygen system. I remember a young man that always needed that system. When the power went out, they looked for help to go to the hospitals, but all of the roadways were blocked because it was in the middle of the storm and he passed away.

- *Mayor, Community #9*

I believe that "direct impact" is death caused by the hurricane and "indirect impact" was after the hurricane for not having electricity, a respiratory failure, couldn't use the machine, didn't have medication. Those were indirect deaths. - Emergency management personnel, Community #7

These deaths that resulted from the inability to operate medical equipment appear to have occurred irrespective of a community's baseline level of hospital access, and were mostly described as deaths that occurred in residents' homes.

Another situation we saw when we visited different communities with bedridden people that needed equipment or ventilators, electricity. When electricity collapsed for these people, many of those people died in their homes, the family doctor would go because they had been bedridden for 15 years and had a condition that was diagnosed. Then, the condition worsened, but it's not documented as a consequence of the lack of electricity and necessary equipment. - Municipal employee, Community #5

...my father was gravely ill too, in fact he died a little after the hurricane...he was bedbound - all this process of the hurricane - he had an illness...already practically in its last stage, which is what is known as Lou Gehrig's disease. Complications precisely due to the lack of utilities...yes, there were deaths. - Mayor, Community #7

Families had corpses in their homes for three days with ice, with the little ice they could find. The person did not receive any service. Did not have electricity, needed equipment, oxygen. He didn't have those. So, he died there. But we had to go get him, and it was a difficult process. His neighbor went through this at the same time. We had ten, nine people that depended on equipment that eventually died. - Mayor, Community #8

Theme 6: Emergence or exacerbation of mental health disorders was widely reported, especially among individuals living in communities with lengthy power outages and among those experiencing lapses in prescription medications for these disorders.

Eight out of the 10 selected communities identified the decline in individuals' mental health as one of the biggest threats to health and safety post-hurricane (Communities 1, 2, 4-8, 10), with communities specifically mentioning concerns about depression, anxiety, and post-traumatic stress disorder. Participant responses indicate that some individuals had pre-existing mental health disorders that were exacerbated post-hurricane, while other individuals experienced the emergence of a mental health disorder or negative mental health impacts as a result of the hurricane's severe consequences and the lengthy recovery period that followed.

The panic, the panic, the nerves, many people sick with nerves needing to go to the hospital and be hospitalized. - Mayor, Community #7

Older people, especially, are the ones that get depressed. A lot of depression. - Municipal employee, Community #8

We had a lot of cases of depression, well, caused by trauma, right? Many people did not expect the impact we experienced. - Community leader, Community #5

Two respondents mentioned lapses in access to medication for the management of mental health disorders as a contributor to declining wellness and even disappearance.

Many people didn't have medications...for their mental health, critical. As a result of the lapse in medication for mental health, many people started to get depressed and arrived here crying. - Emergency management personnel, Community #4

We had some particular situations that left a mark on us. We have a colleague that disappeared after Hurricane Maria, we still haven't found her, a co-worker that was undergoing psychological treatment, and what happens? The doctor closes the offices after the hurricane and she ran out of medications and she disappeared. We don't know where she is. In Bahía Cortés, we were with the press, search teams were made, we haven't found her. But I imagine the mayor told you about the man who committed suicide in the morning and in the even the power had come back after 6, 8 months without electricity. I mean, we experienced emotional impact, more than 3 thousand homes were lost. - Municipal employee, Community #5

Mortality related to declining mental health. Three communities described cases where the hurricane's impact, especially destruction of homes and property and extended electrical outages, contributed to death by suicide of residents (Communities 1, 5, 10).

Another thing in terms of health was the anxiety that it produced in the town. Suicide attempts, suicide that happened because of living in those conditions for so long and it was one of the situations that also greatly concerned us. In one day, two people committed suicide, on one occasion, one morning, they found a person who committed suicide in the morning and that night electricity came back to where he lived. - Mayor, Community #5

On one occasion, we received information from social workers that worked in schools and they informed us that they were getting, all of the sudden, a lot of cases of kids that were expressing suicidal thoughts - with the desperation, without internet, without electricity, without food, it's so hard. -Communications, Community #5

The cases of suicide increased after Hurricane Maria. The people that could not deal with the situation previously had to make a decision that was not the most adequate, across all of Puerto Rico because it was not just here, all of Puerto Rico. - Emergency management personnel, Community #1

For me, what did take off, not astronomically, but what did take off for me were the suicides because in this position one finds out, one finds out every time there is a situation like this one and it got to a point where one says "My God, another one!" like... This is a small town, so when everyone knows each other and someone says, "hey, so-and-so took his life," it shocks you. I believe it is related to the losses...many losses at the same time. People still come to my office that never got any assistance. Understand that they submitted their applications to FEMA, they did their applications with insurance, I mean... Anyway, the insurance didn't pay up. FEMA denied their claims because they had private insurance. That type of situation. - Municipal employee, Community #10

Discussion

This study sought to understand hurricane impact-related factors and community attributes that may have contributed to disproportionate morbidity and mortality among individuals with NCDs following the impact of Hurricane Maria in Puerto Rico. We examined the intersection of these community attributes and the type and duration of hurricane impacts and cascading failures in infrastructure and key resource sectors to understand the effects on individuals with NCDs. The communities selected for this study represented a great degree of heterogeneity in terms of underlying context and post-hurricane situation, helping to better understand the breadth of impacts. There were a number of populations that were characterized by study participants as being at highest risk for excess morbidity and mortality post-disaster, and they were identified by participants based on their: a) specific health conditions, including individuals with chronic kidney disease, diabetes, cardiovascular disease, respiratory disease, and mental health disorders; b) requirements for NCD management/treatment, such as continual or regular use of medical equipment, oxygen, prescription medications, and/or other treatments; and additional factors that compounded risk, such as c) advanced age; and d) limited mobility.

The vulnerability of these high-risk groups was closely related to the *type and duration of impact* from the hurricane, including flooding and road blockages from debris and landslides. There were notable variations in the degree to which these shorter-term hurricane impacts affected NCD management based on geography/remoteness and type of terrain of the municipality. Hurricane impacts resulting from flooding and wind were more commonly described among coastal communities, where hospitals were reported to be damaged by wind and pharmacies, laboratories, and other health-related facilities flooded. For this reason, baseline access/proximity to healthcare services appeared to be a poor indicator of healthcare access post-hurricane - populations with good access to life-saving health services pre-disaster found themselves medically underserved post-hurricane, dependent on local hurricane damage.

Study results indicated that the impact of road blockages tended to more severely affect individuals living with NCDs in more remote communities prone to landslides, in particular inland municipalities with mountainous terrain. These impacts occurred more so over the intermediate and longer terms. While dialysis patients were affected across all selected communities, patients from these communities, and in particular those communities with the lowest baseline dialysis access, were the most severely affected by road blockages, given the lengthier reported time required to clear roadway obstructions from landslides compared to other impacts, thus delaying dialysis treatment to a critical point. Regardless of municipal remoteness or terrain, a majority of communities identified barriers to dialysis as one of the biggest threats to health post-hurricane, either due to dialysis unavailability from center closures or center inaccessibility from impassable roadways. These findings are consistent with other studies that have documented the vulnerability of dialysis patients following disasters due to missed dialysis sessions, including as a result of transportation-related barriers (10,21,44,50,58,68,69,78,93,94); however, this study identified considerable variation in the length of time that roadways were blocked based on baseline access and community location and topography, highlighting the importance of considering these factors during preparedness for natural hazards of this magnitude.

Furthermore, guidelines for dialysis patients on how to prepare for natural hazards vary widely. Most publicly available guidelines would under-prepare patients in contexts of catastrophic disasters similar to those seen following Hurricane Maria. Current guidance would fall short of protecting patients experiencing severe damage to infrastructure and extended power outages. For example, some guidance relies on infrastructure and resources that are less likely to be available following severe events, such as reliance on telecommunications to coordinate care and verify service availability or the designation of primary and secondary dialysis centers without consideration of actual post-disaster roadway access conditions or other impacts (95–98). Guidelines for dialysis patients should be expanded to include information on how to prepare for scenarios following catastrophic disasters, including expanded options for

local dialysis treatment that addresses transportation-related, roadway access barriers, and damage to dialysis centers that are likely to occur, and persist, post-disaster.

The vulnerability of the high-risk groups identified by study participants was also closely related to *key resource interruptions* post-hurricane, namely electricity, generators, diesel fuel, and potable water. The resource interruption with, by far, the most pervasive negative consequences for NCD management and treatment was electricity. The consequences from electrical outages were felt across all 10 communities and were reported to result in substantial morbidity and mortality among those with NCDs. Importantly, electrical supply and access to generators was described as being vital both in clinical and home-based care settings since many individuals relied on medical equipment use at home. The effects from electrical outages and generator failures were immediate – a reliable electrical source was vital not only for the operation of medical and dialysis facilities and pharmacies, but also for the use of life-saving medical equipment and ventilators. Individuals requiring dialysis and medical equipment were immediately the most vulnerable, as most municipalities reported deaths among this population. This finding related to the impact of electrical outages on individuals with NCDs is consistent with other studies (45,99–104). However, this study found that the negative effects from electrical outages following Hurricane Maria extended far beyond the immediate post-hurricane period, with interruptions lasting, in many cases, months at a time and with notable reported disparities between municipalities as well as urban and rural areas. In this time frame, diesel fuel shortages became increasingly pervasive, thus further complicating the operation of generators to power life-saving medical equipment. Lengthy electrical outages (in addition to adverse living conditions) were also widely reported by participants as severely affecting mental health and presenting significant long-term challenges for the refrigeration of medicines like insulin and operation of medical equipment. While the effects of power outages on individuals with NCDs has been described in other studies, the extent and duration of these interruptions following Hurricane Maria far surpassed those previously reported, and the implications of *long-term* power outages for individuals with NCDs, including considerations of fuel supply sufficiency to power generators and mental health consequences, has not been adequately described in the literature (47,69,103,105,106). This finding is particularly relevant to communities throughout the U.S. with aging infrastructure, including electrical grids.

Existing guidelines for patients with NCDs who are reliant on electricity do discuss how to prepare for power outages, but many consist of checklists or planning tools and don't give specific recommendations for how to handle the indirect impacts from disaster, much less in severe or catastrophic disaster scenarios (107). Additionally, some guidelines expect patients to have generators, but low-income populations experience greater barriers to purchasing generators and procuring a fuel supply for an extended period (14,103,108). Overall, guidelines don't recommend that patients prepare for a time period that is in line with the duration of impacts from catastrophic disasters, and tend to rely on resources that may not be available such as telecommunications, fuel to power generators, or ice to cool medications (109). In the case of Hurricane Maria in Puerto Rico, communities had prepared, but not for the possibilities of experiencing power and telecommunication outages that persisted for months at a time, combined with shortages of diesel fuel and few alternatives to refrigerate medications.

Other key resource disruptions that contributed greatly to morbidity and mortality post-hurricane were related to interruptions in the *prescription medication and oxygen supplies*. All selected communities reported impacts from medication shortages, with individuals managing diabetes, mental health disorders, and hypertension reported as most affected, and six communities reporting deaths related lapses in medications. Furthermore, six communities reported oxygen shortages, all of which reported deaths related to this lapse in supply. Remote communities with mountainous terrain experienced the greatest impact from these shortages due to extended road blockages that created additional delays in procurement. While there are studies that have reported the impact of medication shortages on individuals with NCDs, there are less studies that have reported similar findings related to oxygen supplies (12,44,45,47,70,103–105,110,111). Many current patient guidelines recommend storing a 3-7-day supply of medications and inform patients about prescription assistance programs, which require access to internet or telephone (17,18). However, given the experiences following Hurricane Maria, guidelines should be expanded to recommend that patients anticipate the possibility of longer service, transportation, and resource interruptions, and prepare accordingly for catastrophic events, including how to handle medication or oxygen shortages despite preparedness at the household level.

Limitations. There are some limitations to this study that should be considered when interpreting results. First, 10 municipalities were selected out of 78 total municipalities in Puerto Rico, and one inclusion criteria was that the municipality had lower SES. The small number of cases of lower SES communities limits the generalizability of findings to the broader population in Puerto Rico. In order to minimize this limitation, we used a sampling strategy and numerous community attribute variables to increase the likelihood that participants would have a wide range of experiences in terms of hurricane impact. Importantly, low SES municipalities were the most severely affected following Hurricane Maria in terms of excess mortality (84), and study findings are likely applicable to other low SES communities and individuals given that 44% of Puerto Ricans lived in poverty as of 2019 (103,112). While this study does not facilitate an assessment of causal relationships between disaster impact and mortality, findings do provide insight into the factors surrounding morbidity and mortality of individuals with chronic health conditions, as well as contributors to health care system impacts that negatively affected management of chronic disease.

Conclusions

The experiences following Hurricane Maria in Puerto Rico offer important lessons regarding the impact of catastrophic disasters on NCD treatment and management, and are useful for improving community and health system resilience and preparedness for future disasters. There were a number of populations that were identified as being at increased risk for morbidity and mortality post-hurricane, in particular individuals with NCDs that require lifesaving medical equipment, dialysis, and prescription medications. These high-risk groups should be prioritized for future disaster preparedness planning, especially when multiple risk factors are present and there are additional financial barriers to adequate preparedness. The vulnerability of individuals with NCDs was closely related to community attributes and the type and duration of cascading hurricane impacts. Catastrophic disasters introduce additional preparedness considerations for individuals with NCDs. Preparedness guidelines for individuals with NCDs should be expanded to consider these possible impacts as a result of catastrophic disasters, especially with the demonstrated increase both in the intensity of natural hazards and the proportion of the U.S. population with NCDs. Disaster impacts that limit traveling to procure healthcare services or prevent communication with care providers warrant preparedness plans and contingencies that anticipate the need for in-place primary and NCD care, including in local community and home-based settings, when damage to

infrastructure is considerable. Community disaster preparedness should integrate local medical systems that support home-based care to enhance the timeliness and effectiveness of care for NCD patients. Furthermore, compromised treatment and management of NCDs due to the extended duration of interruptions to services and resource availability highlights the need for preparedness approaches that anticipate these longer periods. Preparedness guidance for pharmacies, medical offices, and specialized care units such as dialysis centers should consider planning for a network collaboration between different units and standards for equipment. Disaster preparedness guidelines for individuals with NCDs should be expanded to apply lessons learned from Hurricane Maria in order to protect populations with NCDs from excess morbidity and mortality in future disasters.

Abbreviations

GW - George Washington University Milken Institute School of Public Health

NCD – non-communicable disease

SES - socioeconomic status

Declarations

Ethics approval and consent to participate. All study protocols were reviewed and approved by the George Washington University Committee on Human Research (FWA00005645) - Institutional Review Board (IRB), study #NCR191558. All participants provided informed consent prior to participation, and all study procedures were performed in accordance with IRB guidelines for the protection of human subjects and ethical principles outlined in the Declaration of Helsinki.

Consent for publication. Not applicable

Availability of data and materials. The datasets generated and analyzed in this current study are not publicly available to protect participant privacy, and cannot be made available by the corresponding author due to privacy and confidentiality stipulations for the protection of human subjects.

Competing interests. The authors declare that they have no competing interests.

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Authors' contributions.

EA designed the study and instruments; collected, coded, analyzed, and interpreted data; and drafted the manuscript.

AC analyzed and interpreted data; translated illustrative quotes; and drafted the manuscript.

CRVS analyzed and interpreted data and drafted the manuscript.

MJ contributed to study instrumentation; collected, coded, and analyzed data; and revised the manuscript.

CERD contributed to study design and instrumentation; and revised the manuscript.

MIR recruited participants; collected and transcribed data; and revised the manuscript.

CSB contributed to study design and instrumentation; and revised the manuscript.

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Figures

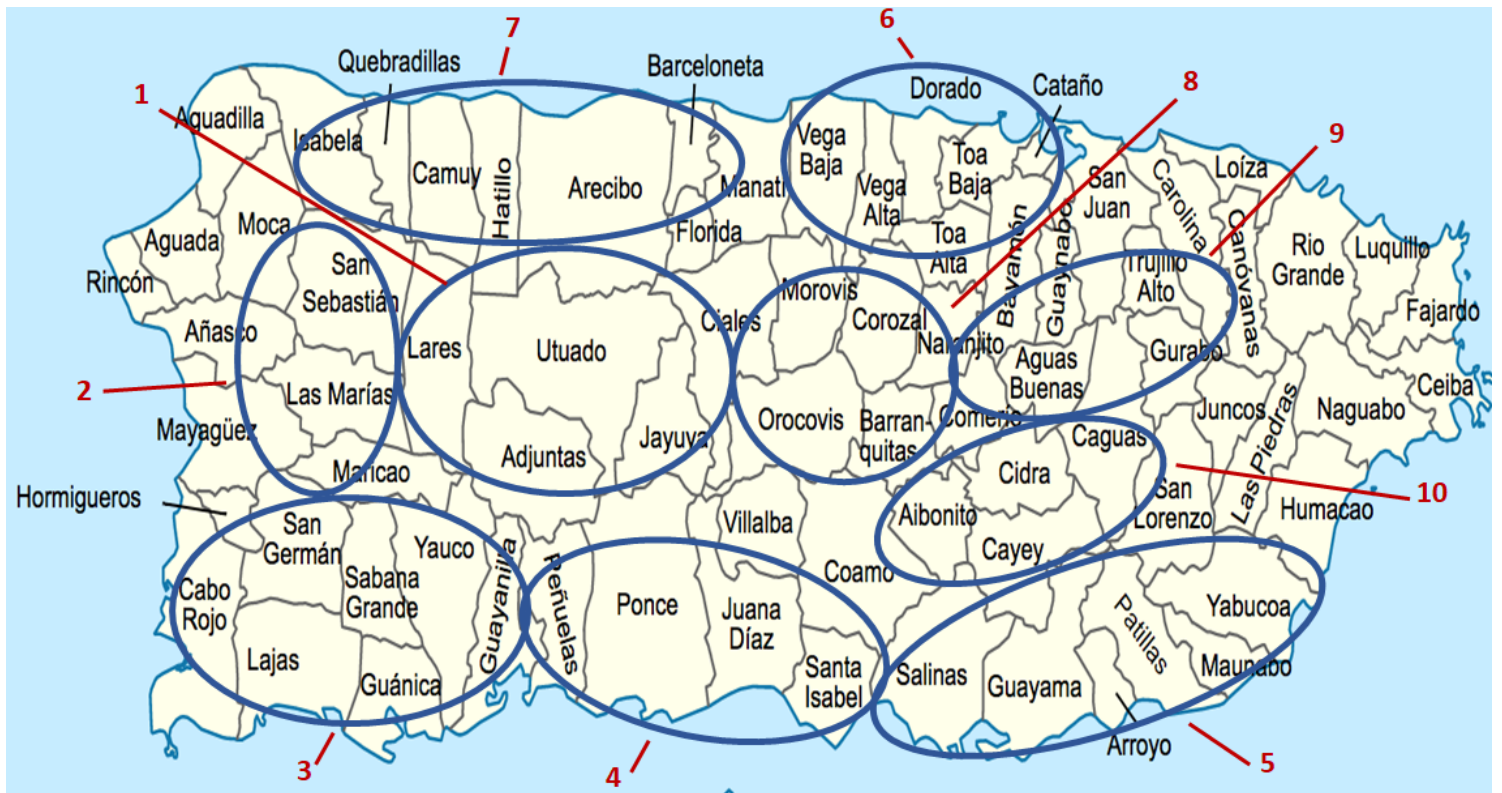


Figure 1

Map of Selected Communities