



Impact of Hurricanes Irma and Maria on Puerto Rico Maternal and Child Health Research Programs

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Abstract

Puerto Rico was hit by two major hurricanes in September 2017 causing great devastation, losing over 90% of the power grid, wireless communication and access to potable water, and destroying many homes. Our research programs: Puerto Rico Testsite for Exploring Contamination Threats (PROTECT), Center for Research on Early Childhood Exposure and Development in Puerto Rico (CRECE), Zika in Infants and Pregnancy (ZIP), and Environmental Influences on Child Health Outcomes (ECHO) are ongoing observational cohort studies that have been investigating environmental risk factors for perinatal health outcomes among Puerto Rican mothers and infants. Our projects paused operations for about two weeks, to begin recovery process and become a source of assistance, retaining 95% of study participants across all research programs. We joined with various groups to ensure the safety and welfare of team members, study participants, community health center partners, and members of the surrounding communities. We learned important lessons about the impact of these hurricanes and the difficulties of the recovery. Major challenges post-hurricanes were access to care and nutrition, maternal stress, and environmental damage. We understood the need to integrate disaster preparedness into our programs' operating procedures and future applications, recognizing that these events will recur. We will grow resilience among our staff, maternal and child health partners, and participants by building on the experience of these two storms.

Keywords Maternal and child health · Natural disaster response · Hurricane · Puerto Rico · Disaster preparedness

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Significance

What is known about this subject? Our research programs: Puerto Rico Testsite for Exploring Contamination Threats (PROTECT), Center for Research on Early Childhood Exposure and Development in Puerto Rico (CRECE), Zika in Infants and Pregnancy (ZIP), and Environmental Influences on Child Health Outcomes (ECHO) are observational cohort studies that have been investigating environmental risk factors for perinatal health outcomes among Puerto Rican mothers and infants. In September, 2017 when the hurricanes hit Puerto Rico, our studies had approximately 450 enrolled participants.

What this study adds? We describe how our research programs were affected by the hurricanes, how we successfully responded to the needs of our team and study participants, and how we were able to quickly resume research activities. By using our programs' close proximity to the storms' impact and recovery, we are able to reflect on the experiences of our team and participants in order to help inform future preparation and resiliency in Puerto Rico and other hurricane prone areas worldwide.

Introduction

The Hurricanes

In September 2017, Puerto Rico was hit within 2 weeks by two category 4 hurricanes, Irma and Maria, an unprecedented occurrence since meteorological events have been recorded by the US National Weather Service. Hurricane Irma passed Puerto Rico on September 6, 2017, causing an estimated \$1 billion in damage and 3 fatalities in Puerto Rico. Two weeks later, on September 20, Hurricane Maria, the largest hurricane to hit Puerto Rico since 1928, made landfall in the southeast coast with sustained 175 mile per hour winds and tracked through over 75 miles of the heart of the island, exiting in the northwest coast. As a result, almost the entire island was left without electricity and wireless communication, about half of households were without water, thousands of homes were destroyed, and countless numbers of people were displaced. The damage is likely to exceed over \$100 billion. The toll of life lost is estimated at over 4500 deaths (Kishore et al. 2018) and over 8 months later, the island is still in recovery with more than 20,000 households remaining without power (USCB 2010; USCB 1931).

Prior to the hurricanes, marked disparities in maternal health and pregnancy outcomes already existed between Puerto Rico and the mainland United States. In recent

years, Puerto Ricans had a 23% higher rate of preterm birth, a 35% higher rate of low birth weight, and 38% higher infant mortality rate (March of Dimes 2016). Additionally, the teen birth rate in Puerto Rico was 67% higher and the rate of unintended pregnancy was 75% higher than in the U.S. as a whole (CDC 2016; Mosher 2012). It is not unreasonable to expect these disparities are likely to widen as it has been shown that planned and unplanned pregnancies increase following a natural disaster (Cohan and Cole 2002; Hapsari et al. 2009).

Natural disasters also have been shown to have consequences on infant health outcomes, increasing likelihood of reduced height and weight outcomes, lower APGAR scores, and psychiatric distress (Chang et al. 2002; Salazar et al. 2016; Tan et al. 2009). These health risks to expectant and new mothers and their infants can be seen in cases of both primary and secondary natural disaster exposure (Cordero 1993). Primary exposures from the event itself include physical dangers such as a structural collapse, floodwater damage, or acute exposure to ash and particulate matter from a volcano. Secondary exposures occur in the aftermath of natural disasters and may result from prolonged periods of extreme stress, persistent malnutrition, environmental exposures, or extended economic hardship. Indeed, since the landmark study of an Appalachian flood, environmental sociologists have long understood that many disasters are partly or wholly human-made (Erikson 1976). Due to the prolonged and complex recovery effort in Puerto Rico, the secondary exposure risks are likely to be more harmful than the hurricanes themselves. The long history of colonialism and environmental injustice in Puerto Rico will likely play a role in secondary exposures (Brown et al. 2018; Rodriguez-Diaz 2018).

The storms have had a tremendous impact on the Puerto Rican population beyond loss of life, injuries and destruction. They have caused major disruption in economic life, manufacturing, and research activities. We describe the impact of the aftermath of these storms on our NIEHS- and EPA-funded research projects in Puerto Rico, and share lessons learned to improve resilience by enhancing preparedness for future events.

The Research Program

The Puerto Rico Testsite for Exploring Contamination Threats (PROTECT), a Superfund Research program funded by the National Institute of Environmental Health Sciences (NIEHS) since 2008, examines the role of environmental factors on preterm births in Puerto Rico. PROTECT's core biomedical research relies on the data collected through a cohort of pregnant women living in Puerto Rico's northern karst region. Biological samples are collected throughout pregnancy and complemented with detailed questionnaires

to address education, economic status, nutrition, product use (i.e., personal and cleaning products), social support, and maternal stress among others. Nearly 1600 pregnant women have been recruited and about 1200 have delivered live births. The Center for Research on Early Childhood Exposure and Development in Puerto Rico (CRECE) began in 2014 and is jointly funded by NIEHS and EPA. CRECE studies how mixtures of prenatal environmental exposures and other factors affect the health and development of infants and children. CRECE recruits and follows infants born to PROTECT participants for up to 4 years of age with pediatric and neurodevelopmental testing at 6–12 month intervals. Beginning in 2018, mothers and infants in PROTECT and CRECE are recruited into the Environmental Influences on Child Health Outcomes (ECHO) Program, which investigates ways in which early exposures to a range of environmental factors influence the short- and long-term health of children. PROTECT, CRECE, and ECHO are multi-institutional research programs led by Northeastern University and include the University of Puerto Rico (UPR) Medical Sciences Campus and the Mayaguez Campus—the engineering campus for UPR, the University of Georgia, University of Michigan, West Virginia University, and the Silent Spring Institute, representing a true example of team science (NU 2018a, b).

Zika was introduced in Puerto Rico and rapidly became a major epidemic that swept throughout the island after emerging in almost all Latin American countries in 2015. This vector-borne viral disease is the first to be recognized as a human teratogen and Puerto Rico was the first jurisdiction in US soil that had local Zika transmission. The need to study the risks of Zika in pregnancy led the National Institutes of Health (NIH) to develop a consortium of research centers in Latin America and Puerto Rico to develop a large international cohort study of pregnant women at risk for Zika infections. The PROTECT/CRECE team joined the consortium and began the enrollment of pregnant women for the Zika in Infants and Pregnancy Study (ZIP) in 2016 (NIH 2016).

The activities of PROTECT, CRECE, ECHO and ZIP include recruitment and follow-up of expectant and new mothers, all program activities are reviewed and approved by Institutional Review Boards, and all participants provide informed consent/assent for study participation. Investigators and staff from multiple collaborating institutions travel on a regular basis to Puerto Rico, and communications with the teams outside Puerto Rico is on a nearly daily basis. Our headquarters in Puerto Rico are at the University of Puerto Rico's Medical Sciences Campus in San Juan and our research field clinic is located in Manatí, Puerto Rico, in the northern karst region. Our research activities are made possible through research partnerships with three Federally Qualified Community Health Centers (FQHCs) in the

north karst region, located in Morovis, Ciales, Camuy, and a private OB/GYN clinic in Manatí, as well as partnerships with two hospitals, Manatí Medical Center and Metro Pavía Arecibo Hospital. All were drastically impacted by the hurricanes and their aftermath; the devastation in the small mountain towns of Ciales (pop. 19,000) and Morovis (pop. 32,000) made national headlines after suffering direct hits by the eye of Hurricane Maria (CBS News 2017; NBC News 2018; NY Post 2017; NY Times 2017).

Disaster Response

In preparation for the hurricanes, our team developed a contact list of each team member to reach each other after the hurricane. Approximately 20 individuals from our research group resided in Puerto Rico, including four investigators, five nurses, a laboratory technician, a program director, several data and laboratory coordinators, field staff coordinators, and several student trainees. In the days prior to the hurricanes, we physically secured our offices and laboratories, but the preparation did not foresee the tremendous destruction that was coming. Our post-hurricane communication plan was based on using telephone lines, both wireless and land-based, but nearly 90% of wireless telephone towers were destroyed and the northern karst region lacked telephone communications except in some select areas along the major east–west highway. As a result, it took nearly a week to reach most of the staff and in one case it took nearly 2 weeks to establish contact.

Two of us, who were outside of Puerto Rico at the time of the hurricane were not able to return until October 3, 2017, on one of the first commercial flights that allowed civilians aboard. The staff met to assess their personal situation and that of study participants, assess the damages to our facilities, and to determine steps needed to resume study activities. Hurricane María touched our staff's lives directly: two lost their homes completely, six reported they had no water, and no one had electricity. Our first concern was ensuring our team all had food and shelter, and we immediately equipped our staff with personal water filters, solar-powered battery packs for keeping cell phones charged, and other supplies. Once our staff's safety was ensured, the immediate next goal was restarting operations of our research programs, contacting our participants, and assessing their needs and help address them through various resources.

Like our study staff, reaching most participants was difficult because most wireless service was offline. Through meeting the participant at the clinics, persistent phone calls, and visiting them at their homes, we were able to locate most participants within 6 weeks, though contact with others took months, and a few have yet to be contacted were lost to follow-up. Our all-projects retention rate for participants who

were enrolled when Hurricane Maria struck reached 95.5% (430 of 450 total participants). Although some study visits were missed, our team persisted in efforts to make contact, and were able to reach and continue study activities with 93% of ZIP mothers and infants (164/176 and 42/45 participants, respectively), 98% of PROTECT mothers (81/83), and 97% of CRECE children (143/147). The outstanding retention rate for participant in our studies is due to the excellent rapport that our team has developed with our participants. Because members of our team are from the same communities as our participants and develop relationships throughout their pregnancies, we have developed trust and confidence with our participants that maximizes study retention rates. Our research projects are integrated with regular health care and preventive services, which demonstrates to participants that they are not being subjected to extractive research practices from outsiders who do not deeply care for their well-being. The previously mentioned Zika intervention was one example of how our team stepped outside the routine aspects of the research program in order to respond to a major health crisis. In many cases, while our team was reaching out to make contact with our participants, the participants were also making efforts to get in touch with us, as our team was a crucial source of information and support for them during the recovery period. The demographic characteristics of the few participants who were lost to follow-up do not differ from the remaining cohort and we do not expect results from our studies to be impacted or biased.

Discussions among collaborators, study participants, and staff helped our team to identify high priority needs in the communities. Changes to the environment following extreme weather events may expose expectant and new mothers to new health risks via pathogenic organisms and environmental toxicants. For example, following hurricanes Irma and Maria there was an increase in leptospirosis infection, spread through flood water contaminated with infected rodent urine. Another example of health risks as a consequence of the hurricanes is the air quality that was compromised due to widespread use of generators that are fueled by propane, gasoline, and diesel. In addition to structural damage and displacement, flooding may lead to mold growth in homes, which has been shown to have negative impacts on birth outcomes (Harville and Rabito 2018). Furthermore, the effect of the hurricanes' flooding on the mosquito population and the resulting effect on arbovirus transmission rates is unknown. Lastly, the lack of electricity has left many people without air conditioning and susceptible to extreme ambient temperatures that negatively impact birth outcomes (Ha et al. 2017a, b, c). Recovery from the environmental damage to the built and natural environment in Puerto Rico will require years of reconstruction and mitigation due to the magnitude of the catastrophic impacts caused by the hurricanes across the island. As mentioned above, the incorporation

and implementation of adaptive strategies are being introduced to further reduce population vulnerability and harm due to the possibility of re-occurrence of natural disasters in Puerto Rico.

Responding directly to the needs of the communities, the PROTECT/CRECE/ZIP teams on the ground in Puerto Rico mobilized students at the University of Puerto Rico School of Public Health to pack and distribute donated goods and materials that were received from multiple sources, including the University of Georgia, University of Michigan, Northeastern University, and many individuals. Our staff obtained water filters through collaboration with the Society of Jesus and their High School in Puerto Rico and trained personnel at collaborating clinics and individuals on the use of the filters. Additionally, PROTECT/CRECE/ZIP have been able to use a cultivated bond with the communities to provide valuable networking in order to match other hurricane relief efforts with community needs. PROTECT/CRECE/ZIP also collaborated with the University of Rochester and the Puerto Rico Association of Primary Health Care to deliver mobile clinics to local FQHCs, schools, community organizations, and libraries. We worked with several organizations to distribute over 50 water filtration systems that provided dozens of gallons of potable water daily to people in the FQHCs and adjacent communities. Our teams worked tirelessly to distribute countless mosquito repellent and nets, baby wipes, diapers, flashlights, batteries, hand sanitizers and other personal hygiene items, as well as personal-sized water filters for individuals and families.

Continued contact with participants allowed us to monitor unmet family needs, such as nutrition. We quickly noticed that lack of adequate access to nutrition for woman and their infants may be an overlooked obstacle during the hurricane recovery period. In Puerto Rico, following the hurricanes, families that were accustomed to widespread availability of meats, fruits, and vegetables were limited to an insufficient selection of non-perishable food stocks. Many available food products were high in sodium and low in nutrition. We learned that although FEMA was distributing food, it was not appropriate for pregnant women, babies, nor for persons with diabetes, cardiovascular disease, and kidney disease because it contained large amount of carbohydrates (sugar) and sodium; an issue that already existed due to nutritional/food deserts in Puerto Rico and exacerbated by the hurricanes. An example of the consequences of poor nutrition during a recovery period was seen in Jamaica following Hurricane Gilbert where there was an increase in neural tube defects due to staple crop losses that were a primary source of folic acid (Buekens et al. 2006). Recovery efforts must be sensitive to the nutritional needs of mothers and infants, and be supportive of their specialized needs.

Access to continued health care was a major issue in the wake of the hurricanes. One aspect was securing

transportation to pharmacies and clinics due to loss of public transit. Further, many pharmacies were closed due to lack of electricity and those the pharmacies that were open usually lacked internet access to verify prescriptions. Access to adequate perinatal care following a natural disaster can be a challenge for new and expectant mothers. Women are more likely than men to receive inadequate health care following a natural disaster and the consequences are more severe for pregnant women due to the needs of the developing fetus (Carballo et al. 2005; Richter and Flowers 2008). Challenges to maintaining the continuity of care include the physical disruption of transportation systems, communication systems, evacuations and migration, and prioritizing other emergency response activities. Difficulties in receiving routine medical care, paired with disrupted vaccination schedules and unsanitary environments, create an elevated health risk that surpasses the normal health risk of inadequate perinatal care (Watson 2007).

Another hurricane/natural disaster related risk to the health of our participants are mental health challenges that may manifest or worsen in the aftermath of the hurricanes. Maternal stress, depression, and anxiety during pregnancy have been associated with negative health outcomes in infants (Ulrich and Petermann 2016). The drastic lifestyle changes following a natural disaster constitute a dramatic departure from normality and may result in an increase in stressors and a decrease in support networks. The consequences may not be limited to elevated stress as it has been shown that post-traumatic stress disorder (PTSD) may also lead to behaviors such as smoking, substance abuse, excessive weight gain, and inattention to proper prenatal care (Morland et al. 2007). Psychological challenges are not limited to the mothers, as infants born to mothers exposed to Hurricane Katrina had difficult temperaments associated with their mothers' mental health (Tees et al. 2010). While managing perinatal health care during and after a natural disaster, it is vital to consider maternal mental health.

New study recruitment and follow-up evaluations for the ZIP project resumed within 2 weeks after Hurricane María and within a month for PROTECT and CRECE. Our quick return to study operations was not only due to external resources, such as donated power generators and our close proximity to the Manati Medical Center, but also was related to our staff's commitment and sheer determination. Importantly, the staff put forward a combination of self-care for the staff, dedication to the research enterprise, and commitment to practicing broad public health that goes far beyond just "environmental public health." Participants's own commitment to keeping up with clinic visits for research purposes was facilitated by longstanding trust that the team had cultivated, and that "research altruism" energized staff (Carrera et al. 2018). Even today the utility for more than 1 year following Hurricane Maria, and communication services

are remained intermittent and unreliable, and browning and loss of power continues to be expected. While we were able to reach pre-hurricane recruitment rates and averaged approximately 35 new participants per month, there remain some challenges to study activities and we have had some participant loss.

Despite the many challenges to research activities during the recovery period we did not lose data or biologic samples. The laboratory freezers containing our biologic specimens and the computers supporting the electronic storage of our data bases were fortunate to be supported by infrastructure that did not suffer a loss of power during or after the hurricanes. The University of Puerto Rico's Medical Science Campus was supported by two backup generators that allowed for redundant back-up power supply. Members of our team visited the campus regularly in the days following the Hurricane Maria in order to ensure the integrity of the biologic samples stored in freezers. Following the hurricanes, another generator was added to the facility with a line specifically designated for supporting the laboratory.

Discussion

In recent years, extreme weather events have been increasing in frequency and have caused billions of dollars in losses to the United States and its territories (Coumou and Rahmstorf 2012). According to historic records of Accumulated Cyclone Energy (ACE) in the Northern Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, 2017 was the most active hurricane season since 2005, and September was the most active month ever recorded (NHC—NOAA, 2017). Climatology models have been used to predict an increase in tropical cyclone activity in the 21st century (Knutson et al. 2017) and studies have shown the power dissipation index to be associated with rising sea surface temperatures (Coumou and Rahmstorf 2012).

It is increasingly evident that populations in geographic regions susceptible to extreme weather events must be prepared ahead of time to protect their vulnerable populations. Going forward, our team recognizes the importance of being prepared for the next emergency and strives to educate our staff, study participants, and collaborators on preparedness strategies. Our first step will be to work internally to develop our own capacity, focusing on key core competencies in an emergency, including review of the chain of command, correct use of emergency equipment, and the protection of workers' physical and mental health during emergency situations.

Our research projects were successful in responding to the emergency, supporting the staff and becoming a center of orientation and support among the study participants and their families. As our program operations stabilize, we will

formally train our staff and initiate an education program on basic emergency preparedness focused on maternal and infant health. Using strategies that have been promoted by leading agencies in the fields of emergency preparedness, we will educate our participants emergency preparedness strategies focused on extreme weather events. These strategies will include, among others: (1) developing an at-home emergency kit; (2) understanding key concepts about maternal nutrition standards for expectant and new mothers and their families, and how to be prepared to meet them in an emergency setting; (3) being prepared to support breast feeding in an emergency situation; and (4) becoming familiar with the basic knowledge of the birthing procedures in an emergency situation.

The Red Cross recommends that families prepare themselves with basic supplies that may be needed in the event of an emergency or a disaster. This list includes (but is not limited to): water, non-perishable food, flashlight, batteries, radio, first aid kit, personal hygiene items, family and emergency contact lists, supply of medications, a multi-tool, and cash. Particularly important to pregnant woman (and others with medical conditions) is to have a copy of personal documents, including medical records, to be prepared in the case of evacuation. If possible, in Puerto Rico's case, it is useful to have medical records in both English and Spanish. Additional medical supplies that may be specific to pregnant women and new mothers include prenatal vitamins and supplies for gestational diabetes (American Red Cross 2017).

During pregnancy, a healthy well-balanced diet becomes more important and an unhealthy diet is more consequential. In the aftermath of a natural disaster proteins, fruits, vegetables, and whole grains may not readily available, and the vitamins and minerals necessary to maintain a healthy pregnancy may be more difficult to find. During pregnancy, folate and iron are necessary to prevent anemia; and vitamins and minerals, such as calcium, magnesium, vitamin E, C, and beta carotene are important for reducing the occurrence of pre-eclampsia. For these reasons, it is recommended that pregnant woman stockpile at least a week's or more supply of nutritionally-balanced food items and to have on hand an extra supply of prenatal vitamins (Ewing et al. 2008).

The United States Breastfeeding Committee recommends that emergency preparedness should include provision for the protection, promotion, and support of breastfeeding as well as and safe infant and young child feeding. Breast milk constitutes the safest and healthiest source of nutrition for infants during emergency situations. During and after natural disasters there may not be clean and safe drinking water or means to sterilize infant feeding utensils as both required for infant formula preparation. On the contrary, breast milk is readily available and sanitary without the need of cleaning feeding supplies or heating sources for preparation. Additionally, breast milk is nutritionally perfect for the infant

and constitutes an ideal source of hydration. It Breast milk contains antibodies that are protective against diseases, especially respiratory tract infections and diarrhea (the most common cause of morbidity and mortality during emergency situations). Lastly, breast feeding has been shown to lower stress and anxiety to both mother and child (United States Breast Feeding Committee 2011).

Unexpected events, such as natural disasters, may prevent a woman in labor from traveling to a hospital or birthing center. While the timing is unfortunate, the birthing process can be done safely at home in an emergency situation when there is no other option. The American College of Nurse-Midwives suggests that expectant mothers prepare for emergency at-home births with a kit equipped with basic supplies for the birthing process and infection control. While the information should never be considered a replacement for a trained professional such as an obstetrician or midwife, knowledge of the birthing procedure could be lifesaving in an emergency circumstance (Williams 2004).

As was the case with Hurricane Katrina in the Gulf Coast, local programs such as ours are typically a major component on the front line of disaster response. In the wake of the devastation caused by Hurricanes Irma and Maria, it is essential to use our programs' experiences in order to be better prepared for next time. By using our programs' close proximity to the storms' impact and recovery, we are able to reflect accurately in order to prepare our programs for the future and learn more about the health impacts of natural disasters. As our team transitioned from continues to struggle with the relief efforts back to research, we found ourselves in a unique position to contribute to the scientific literature regarding the impacts of natural disasters on maternal and child health.

The longstanding enrollment of expectant mothers into the PROTECT and ZIP cohorts prior to the hurricanes provides a unique opportunity to make comparisons to an established baseline of exposures and outcomes related to maternal health in this population. The ZIP and PROTECT cohorts had over 500 pregnant participants enrolled at the time of the hurricanes or enrolled shortly after, during the hurricanes' aftermath. Using the many years of accumulated data from our cohorts, we are currently exploring differences in birth outcomes (preterm birth, birthweight, and pregnancy loss) from before and after the hurricanes. Additionally, we are conducting in-depth surveys with PROTECT and ZIP participants to investigate their hurricane related experiences and traumas, which will be used to explore potential associations with adverse birth outcomes. Specifically, among the PROTECT participants, we are also exploring hurricane-related environmental exposures, including biomarkers for phthalates, pesticides, polycyclic aromatic hydrocarbons, and heavy metals by comparing them to levels in our participants prior to the hurricanes. It is goal to use the experiences

of our team and participants during the hurricanes to help inform future preparation and resiliency for maternal and child health in Puerto Rico and other hurricane prone areas worldwide focus on using our experiences to improve Puerto Rico's maternal and child health resilience.

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Compliance with Ethical Standards

Conflict of interest The authors have no conflicts of interest to disclose.

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