

A protest in Puerto Rico in June, 2018 highlights one estimated death toll for Hurricane Maria.



DEATH COUNTERS

When scientists tallied how many people perished in Hurricane Maria and other crises, they battled statistical, political and physical hurdles. But new methods are in the works.

BY CARRIE ARNOLD

In the pale predawn hours of Old San Juan last February, Neysha Burgos-Nieves and Hector Rosado loaded a battered black car with everything they might need for a few days — from bottled water and protein bars to flashlights and a change of clothes. Their first stop was more than two hours away, high in Puerto Rico's isolated central mountains. Although it had been more than four months since Hurricane Maria had slammed into the island in September 2017, much of the US territory remained without electricity, water or mobile-phone service. If Burgos-Nieves and Rosado ran into trouble once they left the relative safety of San Juan, the two research assistants would be on their own.

Their goal was simple, if ambitious: calculate the excess mortality from Hurricane Maria. In other words, determine how many people perished in the months following the storm and subtract the number of people who, on average, probably would have died anyway. Burgos-Nieves, Rosado and their adviser Domingo Marqués, a clinical psychologist at Carlos Albizu University in San Juan, had no idea what that estimate might be. But anyone who had spent time in Puerto Rico knew that the excess deaths were much higher than the government's official count of 64.

It was gruelling work. Many of the researchers in Marqués's team had lost electricity, water and, in some cases, their homes. Nearly all admit to breaking down in tears at least once. "Every day, you would hear more stories of suffering. It was exhausting," Rosado says.

But the project held a deeper meaning than simply counting those who had died. "We were giving light where there was a lot of darkness. We gave light to the truth," Burgos-Nieves says.

Throughout history, humanity has lurched from one disaster to the next. Some are born of nature's capriciousness; others arise from

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SOURCES: TOP: REF. 5; BOTTOM: REF. 6

our own actions, as genocide and war swallow parts of the planet. Either way, someone has to count the dead. And in the aftermath of catastrophes, the amount and type of aid that flows to hard-hit areas depends on those estimates. Normally, mortality counts are the function of governments, which collect death certificates and keep the public informed. A death toll should theoretically be as straightforward as tallying those who have perished. Nothing about disasters, however, is simple.

Not everyone has access to death-certificate information, nor do governments always collect and release accurate data. In Puerto Rico, the hurricane overwhelmed a fragile infrastructure that was already struggling to provide health care and other basic services. The challenge of calculating mortality rates there is not unlike the situation researchers face in conflict zones such as Iraq, Syria and Yemen, where infrastructure either never existed or was destroyed. Since the 1980s, epidemiologists have tried to work around these barriers by using increasingly sophisticated statistical methods to estimate death tolls.

Those methods have come under increased scrutiny as the field has attracted new researchers, who argue that such approaches are severely flawed. They say that the uncertainties surrounding these estimates typically span several orders of magnitude, and point to inconsistent survey methods that can yield unreliable results. Such questions about methodology have opened researchers up to strong criticism from those seeking to use mortality estimates for their own political agendas. The result is that no one — not governments, scientists or non-governmental organizations (NGOs) — can estimate precisely how many people are dying as a result of war and other disasters around the world.

But scientists are hoping to change that, using strategies borrowed from wildlife biology and advanced statistics. And, sadly, there is no shortage of new calamities that provide opportunities to test these techniques. Independent studies in Puerto Rico, for example, agree that there were 3,000–5,000 excess deaths on the island after the hurricane — findings that call into question the Trump administration's insistence that it provided adequate assistance to the US territory after the storm.

Determining how many people died in a disaster is more than just academic bean counting, says Debarati Guha-Sapir, epidemiologist and director of the Centre for Research on the Epidemiology of Disasters at the Catholic University of Louvain in Louvain-la-Neuve, Belgium. “Knowing who is most likely to die or suffer health problems as the result of a disaster can tell us where to provide assistance,” Guha-Sapir says.

COUNTING THE DEAD

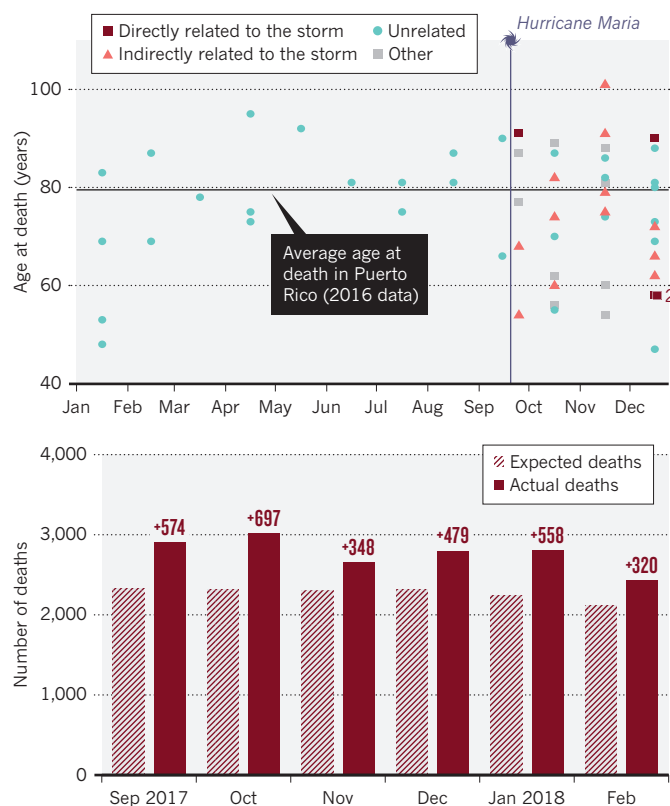
When Guha-Sapir was a young graduate student in the mid-1970s at the Johns Hopkins School of Public Health in Baltimore, Maryland, she met Belgian physician Michel Lechat. For the humanitarian-minded Guha-Sapir, Lechat offered an intriguing new idea, namely that natural disasters could be studied from an epidemiological perspective. Lechat thought that epidemiology could provide a rigorous analysis of who was most at risk of dying should a disaster hit. By targeting these individuals, Lechat argued, aid agencies could more effectively put their scarce resources to work. After Guha-Sapir graduated from Johns Hopkins, she joined Lechat at the Catholic University of Louvain. A chance to test the approach came in 1984, on the heels of a disaster broadcast into millions of homes on the evening news.

At the time, hundreds of thousands of people were dying of starvation across the Horn of Africa. Together with Lechat, Guha-Sapir worked to determine broad-scale risk factors for famine in Africa, with an eye to eventually preventing famine, rather than responding only in the aftermath. Her work culminated in a 1987 report for the World Health Organization, which noted the close links between civil conflict and widespread starvation¹.

A decade later, she started working in the Darfur area of Sudan, where she and her colleagues estimated that 120,000 people had died between September 2003 and January 2005 as a direct result of violent conflict there². That created “a tremendous amount of political fallout”, she says, especially from some NGOs, which thought she had deliberately selected methods that would give an unrealistically low figure. “It’s a problem that’s still going on,” she says about the debates over mortality estimates.

AFTER THE STORM

In a survey of randomly selected homes in Puerto Rico, one team enquired about all deaths during 2017 (top) and extrapolated that Hurricane Maria had killed 4,645 people on the island. Another team studied official documents and calculated how many people would have died if the storm had not hit (bottom). They estimated that the storm caused 2,975 excess deaths.



Nowhere were the stakes in this debate higher than in Iraq. Following the invasion of Iraq in 2003, the US armed forces had kept detailed records about their own military casualties, but no one had taken responsibility for determining the war's effect on Iraqi civilians. In October 2006, as public sentiment against the war grew and on the eve of US midterm elections, a group of scientists published a report in *The Lancet*³ estimating that there had been more than 650,000 excess deaths in Iraq as a result of the US-led invasion.

A team including epidemiologist Leslie Roberts, then at Johns Hopkins University, and Riyadh Lafta, a physician at Baghdad's Al Mustansiriya University, arrived at that number by randomly selecting intersections in 50 towns in Iraq and interviewing the 40 nearest households about how many deaths they knew of or had experienced as a result of the war. They chose that method for security reasons, to minimize the time that survey teams spent in the field. Lafta, who accompanied his assistants on their surveys, was repeatedly stopped by both police and the militia.

“We were taken to headquarters, and they checked us and questioned us about who we were and what we were doing. Luckily, they still respected doctors and they let us go,” Lafta says. Only luck allowed the teams to dodge bombs and bullets.

Their published results triggered a firestorm. Two years later, a competing estimate⁴ was published by the Iraq Family Health Survey, conducted by the World Health Organization. That study estimated that there had been 151,000 excess deaths from violence in Iraq between March 2003 and June 2006 — about one-quarter of what Lafta and his colleagues had found.

Critics have argued that both studies are flawed. The broad approach taken in each — cluster random sampling — was adapted from surveys used to measure vaccine coverage in developing countries. But that is not appropriate for a war zone, says economist and statistician Michael Spagat of Royal Holloway, University of London. Compared with rates



CAROL GUZYZUMA

A farmer in Puerto Rico surveys his flooded property in the days after Hurricane Maria.

of vaccination, mortality rates in Iraq were low, which means that small overestimations of deaths would have had an outsized impact on mortality rates, he says. And violence is never evenly distributed across a population. To get accurate results, researchers need much larger samples than the ones used in these studies.

For their part, Roberts and Lafta stand by their findings, even if the controversy has left something of a bitter taste. Lafta has consulted on follow-up studies, although he hasn't been formally involved. "I got too many death threats, and I feared for the safety of my family," he says.

AN ISLAND IN PAIN

Debates about how best to measure mortality were reignited last year in the wake of Hurricane Maria. Even before the hurricane arrived, Puerto Rico was in trouble. Some 44% of the island's pre-hurricane population of 3.4 million lived in poverty — three times the average US poverty rate. With a government facing bankruptcy, Puerto Rico didn't have the resources to confront a storm like Maria, which had sustained winds of 250 kilometres per hour by the time it hit the island.

In late 2018, physical damage from the hurricane continued to haunt parts of San Juan, one of the least affected regions on the island. On some streets, graffiti-covered sheets of plywood still covered the windows of more than half of the businesses, giving parts of the city a post-apocalyptic feel more than a year after the storm. Blue vinyl tarpaulins covered damaged rooftops across much of the island, a vibrant reminder of just how much rebuilding has yet to be done. It is in this aftermath — what epidemiologists call 'the long tail' — that most of a catastrophe's impact on human health is felt, explains Madelyn Hsiao-Rei Hicks, a psychiatrist at the University of Massachusetts Medical School in Worcester, who has devoted much of her research to understanding disasters.

The vast number of deaths attributable to storms or earthquakes come afterwards, when broken health-care infrastructure can't handle the ensuing spikes in disease and illness. But these deaths can be the most difficult to count. If someone has a heart attack while repairing their home and can't get to the hospital because roads are blocked, is that person's death the result of the hurricane? What happens when someone dies of leptospirosis, a bacterial disease spread in animal urine that contaminates water and soil, after moving debris?

"A death certificate might just say 'cardiac arrest'. That's it. How

are you going to attribute that to a hurricane?" Hicks says. Many of the deaths from disasters and wars are indirect, she says, and so are challenging to attribute to a specific cause.

Even before he started surveying households, Marqués had seen the devastation across the island when he accompanied the US Army Corps of Engineers as they worked to clear wreckage from remote mountain roads in the weeks after the storm. Haunted by the experiences of fellow islanders, Marqués and some of his graduate students continued with their impromptu relief missions over the next few months. Knowledge of their efforts spread and quickly reached Cambridge, Massachusetts, where Harvard University epidemiologists Caroline Buckee and Satchit Balsari recruited the team to conduct the survey to determine the true death toll of the hurricane. Buckee and Balsari launched the project because they were frustrated by the mismatch between the scale of suffering and the government of Puerto Rico's official death toll of 64. After Governor Ricardo Rosselló refused to make death-certificate information public, Buckee and Balsari decided to use an epidemiological household survey to get a more accurate count.

The Harvard team asked Marqués to help with its efforts, and he agreed immediately. So did many of his graduate students, nearly all of whom were still without electricity, water and mobile-phone service at the beginning of 2018.

The scientists used the island's existing 900 neighbourhoods (known as barrios) and classified them by remoteness. Then, the researchers randomly selected 35 households in each populated barrio, creating a stratified random sample. Researchers visited each household, asking families if anyone had died since the hurricane, as well as how long the inhabitants had been without power, water or phone service. The approach was roughly similar to the one used by Roberts and Lafta in Iraq, but Marqués's team was able to include more data and pick a more random selection of houses. They also had access to better census data and had the advantage of studying a discrete event over a shorter time span than the group in Iraq.

Marqués and his students witnessed the long tail of Maria's effects as they criss-crossed the island and catalogued its misery. The team saw individuals who needed dialysis turn yellow and bloated, and people with diabetes grow ever more frail as their blood sugars soared without insulin. Some residents had taken their own lives, unable

to cope. They extrapolated the numbers from this small sample to the island's entire population of 3.4 million (see 'After the storm'). After two gruelling months visiting 3,299 households, the Harvard–Carlos Albizu team had its answer: the storm had caused an estimated 4,645 excess deaths⁵. Although the figure sat within a wide confidence interval that ranged from 793 to 8,498, the findings validated the scale of hardship and trauma the islanders had experienced in the hurricane's aftermath.

Marqués acknowledges that the results are imprecise, but bristles at criticisms from researchers who were not on the ground. "We didn't have access to the data or the best documents, so we had to come up with other ways," says Marqués, whose own home lacked power for 90 days, water for 50 and phone service for 20.

The researchers had to balance their work with their own distress — caring for homeless family members, finding and preparing food, and securing a stable living situation if their own homes were damaged.

CERTIFICATES OF DEATH

While the Harvard–Carlos Albizu study was under review, Governor Rosselló capitulated to political pressure. He asked epidemiologists Lynn Goldman and Carlos Santos-Burgoa at George Washington University in Washington DC to conduct an impartial, independent study of the number of excess deaths that were due to the hurricane, and gave them access to the death certificates. Santos-Burgoa turned to epidemiologist Cynthia Pérez and her associates at the University of Puerto Rico in San Juan for help. The team reviewed 16,608 death certificates filed in Puerto Rico between September 2017 and February 2018.

Reviewing the death certificates was relatively straightforward. But estimating the number of deaths that would have happened if the hurricane hadn't struck — something Marqués's team also had to do — was much harder. Calculating those figures requires detailed data on historical mortality rates, as well as knowledge of immigration and emigration, because many residents of Puerto Rico travel to and from the US mainland for long periods. The study required several months of 16-hour days by Pérez and her team, which were not made any easier by the pushback they received from colleagues, some of whom thought they were stooges setting out to confirm the 'official' death toll. Even going to the cafeteria for lunch was fraught with tension, when Pérez could feel stares and hostility from some of her colleagues.

The team at the University of Puerto Rico and George Washington

her normally poised exterior: "Accounting for death is not a political process. It's not a Republican or Democrat process," Goldman told *Nature*.

The revised numbers might have come too late for Puerto Rico. By the time the new death toll was published, the increased mortality rate had dropped down to typical levels. Federal aid had also largely dried up. Pérez can't help but wonder whether fewer might have died if better numbers had been available sooner.

NO GOOD ANSWERS

The two methods used in Puerto Rico illustrate the extremes of how scientists seek to gather information about excess deaths after a disaster: a less precise but faster and cheaper household survey, or death-certificate information that requires lots of time and intact government collection of crucial statistics. "The reality is, there's no standard method to measure excess mortality," Pérez says.

This lack of standardization has also paved the way for the development of more-innovative methods. Statistician Patrick Ball of the Human Rights Data Analysis Group in San Francisco, California, is testing a technique called capture–recapture, which biologists use to estimate the size of wildlife populations from incomplete data. This strategy compares the number of individuals tagged in an initial 'capture' round with the proportion tagged during a subsequent 'recapture' survey. For instance, if biologists capture and mark 100 wolves and recapture another 100 wolves a month later, 50 of whom are marked, they can estimate the total population at 200 wolves because the recapture revealed that half are marked. Instead of using ear tags or radio collars, Ball turned to names and death tolls from NGOs and media reports. He created a set of complex statistical models that can account for how these lists overlap, and then used that information to estimate the number of violent deaths in a disaster zone.

But the strategy also has its weaknesses. Capture–recapture provides raw numbers on the total killed, but not the baseline mortality rate or the movement of people into and out of an area. The strategy remains a work in progress, he says. He is starting to test it on data from Yemen and Syria. "Is it the best of all possible worlds? No. But has it failed? No," Ball says.

Marqués and his team have made peace with this impossible balance. The work they did documenting the experiences of their fellow islanders wasn't just about counting the dead. Their efforts told *Puertorriqueños* that they mattered. In his office last October, Marqués pulled a photograph off the wall. It was taken more than two weeks after the hurricane, when the US Army Corps of Engineers was still clearing remote mountain roads of debris. Marqués had joined them to provide emotional support in distraught, stranded communities. As their convoy rounded a bend, they came upon the remains of a bridge leading

to a settlement. The only sign of survivors was a plume of smoke rising from a pile of burning rubbish and a sign on a piece of plywood. In the photo, red spray-painted letters read 'Campamento Los Olvidados' — the Camp of the Forgotten.

Marqués returned to that community many times late last year, taking food, water and batteries. Often, his wife and children went with him, all piling into a Toyota pickup to carry supplies and, more importantly, give a connection to the outside world. That, Marqués says, pointing at the photo of the camp residents, was why he worked on the study. "They weren't forgotten," he says. ■

"WE WERE GIVING LIGHT WHERE THERE WAS A LOT OF DARKNESS. WE GAVE LIGHT TO THE TRUTH."

University estimated that the storm had caused 2,975 excess deaths⁶ — a number that the Puerto Rican government quickly adopted as the official figure.

Although the gap between the two estimates is large, both studies revealed that the breakdown in infrastructure — especially medical services — contributed the most to excess deaths. They also show that the Trump administration had not given the island as much aid as it needed.

Both Marqués and Santos-Burgoa say that using death-certificate information provides more accurate results, but they acknowledge that this information is rarely available during crises or in the immediate aftermath. Marqués points out that, although his survey was less precise, it also provided researchers with valuable data about the island's infrastructure in the months following the hurricane, which gave them a handle on which factors played the largest part in post-storm mortality.

After Santos-Burgoa and his colleagues unveiled their results at a press conference last August, Trump angrily tweeted that the excess deaths calculated in the independent report were bogus numbers cooked up by his political opponents. Goldman, who had braced herself for political fallout, didn't expect the report to be featured on Trump's infamous Twitter account. When asked about the incident, a spark of anger flashed across

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