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SPECIAL REPORT

Hurricanes, Pathogenic Diseases, and Health Disparities

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Abstract **Climate change will likely continue to increase the number of hurricanes. After a hurricane, a wide variety of pathogens increase in the environment and disproportionately affect humans. These pathogens include respiratory fungi and viruses, bacteria that cause flesh-eating wound infections, and microorganisms that cause gastrointestinal illnesses. The diseases caused by these pathogens might be contracted from flooded houses during cleanup, spread from person-to-person due to crowded conditions, passed from mosquitoes that increase in numbers after flooding, or spread directly from floodwater. Furthermore, these pathogens harm people with underlying health disparities to a greater degree than people who are not already at risk. Therefore, planning is important to ease the burden for populations already affected by health disparities. Without proper planning, the cost is much higher and has longer-term consequences for populations with underlying illnesses and other health risks.**

Keywords: hurricanes, pathogenic diseases, health disparities, emergency readiness, emergency planning

Introduction

The most immediate considerations when it comes to hurricanes are wind, storm surge, and flooding—each with its own set of fears. A secondary concern to human health that results from hurricanes, however, is the increased level of a wide variety of pathogenic diseases (Maness, 2019). For example, pathogenic diseases can result from exposed wounds that can get infected during hurricane cleanup by organisms such as *Leptospira interrogans* and *Vibrio vulnificus*. Infectious diseases from tropical storms can increase due to crowded conditions that result from people filling up shelters that are opened during emergency responses. Crowded conditions have been linked to increases in conjunctivitis (commonly known as pink eye), gastrointestinal (GI) illnesses such as gastroenteritis commonly caused by norovirus, and other highly communicable illnesses. Increases in pathogenic illness can also result from fungi and their mycotoxins that are found growing in flooded buildings. Fungal and viral respiratory illnesses tend to spike after hurricanes, especially in individuals who have asthma and other underlying issues. Dengue fever, West Nile virus (WNV), and other arboviruses also tend to increase due to surges in mosquito populations after flooding. Additionally, parasites such as *Cryptosporidium* and *Giardia,* as well as bacterial pathogens such as *Salmonella* and *Legionella* spp. increase in floodwaters after hurricanes, increasing the risk of human exposure.

Pathogenic diseases from hurricanes tend to affect people who live in areas that are of lower socioeconomic status (SES) the most (Burrows et al., 2023; Flores et al., 2020). Some people in lower SES areas already have underlying health problems, some do not evacuate because of economic constraints, and yet others cannot afford to travel to obtain needed medications and treatment after hurricane damage. Planning is needed, therefore, to mitigate the devastation from tropical storms, and this planning is most crucial for the disparate groups of people who tend to suffer most. Planning should begin with increasing local awareness of the pathogens that increase after hurricanes and their impacts to health. It is important that people are aware of the environment around them, the role that hurricanes have in increasing human exposure to microorganisms, and how to prevent illness from these pathogens..

Pathogens Increase in Floodwater

The number of potential pathogens often rises in public water systems and private wells after these events. For example, a study by Mapili et al. (2022) involved processing 211 private-well samples in Texas, Louisiana, Florida, and North Carolina after the Louisiana floods (August 2016), Hurricane Harvey (August 2017), Hurricane Irma (September 2017), and Hurricane Florence (August 2018). DNA markers were found for *Legionella pneumophila*, *Mycobacterium avium*, and *Naegleria fowleri* in 15.6%, 17.1%, and 6.6% of samples, respectively. Moreover, 40.3% of all wells tested were found to be positive for coliforms. This study is not unique in its findings.

Hurricanes Irma and Maria both hit the U.S. Virgin Islands in 2017. Almost 3 months after Hurricane Maria, 22 water samples were collected from local households (Jiang et al., 2020). In addition, water samples from 20 coastal locations between St. Thomas and St. John were collected and 3 street runoff samples were collected. Jiang et al. (2020) found that 82% of cistern waters, 30% of coastal waters, and 1 out of the 3 (30%) run-

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off water samples matched *Escherichia-Shigella* gene sequences, while 86% of cisterns, 10% of coastal samples, and 3 out of the 3 (100%) runoff samples matched *Legionella* spp. *Enterococcus faecalis* was present in 68% of cistern samples, 60% of coastal samples, and 2 out of the 3 (67%) runoff samples.

Hurricane Lane hit the city of Hilo, Hawaii, in August 2018, resulting in the wettest period on record in that region. A study that included the collection of coastal water samples after Hurricane Lane indicated the presence of a variety of *Enterococcus* spp., many of which contained virulence genes as well as genes indicating resistances to antibiotics such as rifampin, nitrofurantoin, erythromycin, and tetracycline (Saingam et al., 2021). These *Enterococcus* spp. likely contaminated the waters from urban runoff after the hurricane.

In 2017, Hurricane Harvey decreased the salinity level of Galveston Bay (Yang et al., 2021). This incident in Texas is likely what allowed coliforms and pathogenic bacteria, as well as antibiotic-resistant genes, to proliferate 2 weeks after the hurricane. One study indicated that the fecal coliforms *E. coli* and *Enterococcus* spp. were detected in all samples collected from Galveston Bay. *Salmonella* spp. were detected in low levels in all water samples and at high levels in sediment, while *Vibrio* spp. were detected in water samples and sediment. A similar study also found levels of *E. coli* elevated in bayou samples and an increased presence of antibiotic-resistant genes in these *E. coli* (Yu et al., 2018). As levels of bacteria change in response to environmental changes, it has been suggested that next-generation sequencing could be used to assess water quality and identify which pathogens are present after hurricanes. Next-generation sequencing has already been used to show differences in bacterial constituents in flooded and non-flooded areas (Moghadam et al., 2022).

In 2018, Hurricane Florence flooded areas of Eastern North Carolina that contain large numbers of poultry and swine farms (Niedermeyer et al., 2020). One study after Hurricane Florence focused on isolating *Campylobacter* spp. but instead identified *Arcobacter butzleri* in 73.5% of collected samples. A separate study involved collecting water from various natural sources around watersheds from 48 sites in Eastern North Carolina 1 week after Hurricane Florence and 1 month after landfall (Harris et al., 2021). Methods involved aiming to quantify *E. coli, Salmonella* spp., *Listeria* spp., *and Campylobacter* spp. Results showed that *E. coli* was present in all samples with high levels of *E. coli* in channel and floodwater samples; the channel samples had the highest levels from the 1-month collection. *Salmonella* spp. were present in 6% of samples; nonpathogenic *Listeria* spp. were present in 18% of samples; and *Listeria monocytogenes* was present in one sample. No sample was found to be positive for *Campylobacter* spp.

A study that collected water samples in North Carolina after flooding from Hurricane Michael (October 2017) and Hurricane Florence (August 2018) indicated increased levels of *Salmonella Typhimurium*, *Mycobacterium* spp., and *Enterococcus* spp. in nearly all samples collected from flooded locations (Usmani et al., 2023). *Legionella* spp., *E. coli*, and *Pseudomonas* spp. were increased in a few of the flood samples. The marked increase in *Salmonella Typhimurium* in agricultural locations was attributed to the flooding of swine farms. These studies collectively highlight the serious role that hurricanes play in increasing the number of pathogenic bacteria in wells and floodwater.

Flesh-Eating Pathogens Increase After Hurricanes

Recent news articles have indicated that deaths from the flesh-eating bacterium *Vibrio vulnificus* increased in Florida due to Hurricane Milton and Hurricane Helene in 2024 (Freeman, 2024). The total of 74 cases and 14 deaths in 2024 after the hurricanes exceeded the 46 cases and 11 deaths in Florida in 2023. This same trend also occurred in Florida after Hurricane Ian in 2022. There were 38 cases reported and 11 deaths associated with *Vibrio* spp. after Hurricane Ian (Sodders, 2023): 29 of these deaths were attributed to *V. vulnificus*, 3 to *V. cholera,* 2 to *V. parahaemolyticus*, 2 to *V. fluvialis*, and 2 to other *Vibrio* spp. One person was even coinfected with *V. vulnificus* and *V. parahaemolyticus*. Of the 38 cases, 79% of the cases were men and 80 years was the mean age of the individuals who were infected. It is vital that survivors of hurricanes—especially those with open wounds—heed warnings not to wade in open waters after a hurricane. Increases in *Vibrio* spp. infections after hurricanes are linked to climate change (Venkatesan, 2024).

Mosquito-borne Diseases, Fungal Spores, and Gastrointestinal Illnesses

Mosquito populations are affected by the wind and rains of hurricanes. Hurricanes that occur before the peak of WNV transmission tend to have the greatest affect on the number of WNV cases (Caillouët & Robertson, 2020). Evidence indicates that the number of cases of neuroinvasive disease from WNV is much greater when hurricanes occur early in the season.

In addition to increasing mosquito viruses, wind and flooding from hurricanes can cause fungi to spread through air and water and can also increase the likelihood that fungi could be inhaled or injected directly into human tissue via trauma (Nnadi & Carter, 2021). Examples of fungal pathogens that can increase due to the occurrence of hurricanes are *Candida auris, Cryptococcus gattii* and *C. deuterogattii*. Like many infectious diseases, those infections due to *Candida* spp. and *Cryptococcus* spp. tend to be worse in individuals with underlying comorbidities.

Other fungi, which increase in warm and wet conditions resulting from tropical storms, affect the yield of food crops. For example, *Puccinia striiformis* and *Fusarium graminearum* affect wheat and other cereal crops at a greater rate after hurricanes, which indicates that global warming and climate change leads to decreased crop yield via fungal growth on crops.

In addition to harming crops and spreading at an increased rate because of tropical storm conditions, fungal growth increases inside buildings after hurricanes. A study in San Juan, Puerto Rico, after Hurricane Maria in 2017 showed a change in the number of fungal spores (Vélez-Torres et al., 2022). The researchers examined 10 homes in non-flooded areas and 40 homes in flooded areas and collected indoor and outdoor samples 12 and 22 months after the hurricane. Participants self-reported whether their homes remained dry, were water damaged, or were flooded after the hurricane. Samples were collected, and the fungal colonies that grew on incubated Petri plates were counted. The researchers found that the number of colonies on the Petri plates was greater in flooded homes compared with non-flooded homes. The most abundant genera of fungi found in both indoor and outdoor samples in wet and dry homes after 12 months were *Cladospo-*

rium, *Aspergillus*, and *Penicillium* spp. During the first sampling period at 12 months, *Aspergillus* and *Penicillium* spp. were most common indoors, whereas *Cladosporium* spp. and non-sporulating species were common outdoors. For the second sampling period at 22 months, *Trichoderma* spp. was the most common indoors, while *Aspergillus* spp., *Eurotium amstelodami*, and non-sporulating fungi were the most common outdoors.

GI illnesses increased in North Carolina after Hurricane Florence and Hurricane Matthew, with an 11% increase in emergency department visits due to these illnesses (Quist et al., 2022). The report, however, does not include the cause of the illness (i.e., bacterial, parasitic, or viral). The researchers do note that the increase in GI illnesses was most pronounced in Native American patients over 65 years after Hurricane Florence and in Black patients after both hurricanes. This finding is most likely because these populations have historically been pushed into flood-prone regions of North Carolina. Continued tracking of GI illnesses after hurricanes is necessary so that a prevention plan can be implemented.

Health Disparities and Hurricanes

As with most other health parameters, pathogenic diseases that result after hurricanes are most common in specific disparate groups of people (Flores et al., 2020). For example, a randomized survey of Houston residents after Hurricane Harvey indicated that individuals most affected by physical health issues were individuals who did not evacuate. Often people do not evacuate because of financial constraints. The survey also showed that posttraumatic stress was more likely to affect non-Hispanic Black individuals than non-Hispanic White individuals. In addition, people who lost jobs after Hurricane Harvey and people with disabilities had their access to healthcare most affected. Hurricanes also affect individuals to a greater degree who live in higher poverty, are less likely to own their homes, and reside in more densely populated urban areas (Burrows et al., 2023).

One 15-year study focused on low-income parents who survived Hurricane Katrina, most of whom identified as Black individuals. The researchers sought to better understand disparities after natural disasters such as hurricanes (Raker et al., 2020). This type of study can help guide policymakers and allows service and health providers to better plan and respond after hurricanes. Raker et al. (2020) found that the focus should be primarily on trauma prevention by preventing obstacles to evacuation. The authors also suggested implementing policies that expand access to healthcare. They further cited the need to make social services more efficient by building greater connections within communities. Additionally, individuals affected for the longer-term should be served for as long as possible.

Because climate change is likely to increase natural disasters and affect individuals in disparate groups, planning in any region where there is any hurricane risk is a necessity. Further, the public needs more awareness about pathogens that are known to increase after hurricanes (Maness, 2019). Public awareness should include an understanding of how these pathogens are most often contracted and how to avoid them. People also need to know that many of these organisms affect individuals who are already at risk and who are already living with health disparities to a greater degree. People who experience health disparities based on race, SES, education status, gender, and other factors are more prone to many of the pathogens mentioned in this report that are known to increase after hurricanes. These individuals are more at-risk for:

- being exposed to flesh-eating bacteria such as *Vibrio* species;
- contracting respiratory illnesses caused by fungi, viruses, and other pathogens;
- developing GI illnesses such as those caused by *Giardia*, *Cryptosporidium*, and norovirus; and
- contracting illnesses that are highly associated with crowded conditions.

Planning is crucial to helping people who live in hurricane-prone areas who already experience health disparities. Implementing planned services will mitigate further risks after hurricanes that increase health risks, especially in individuals who are already at higher-risk.

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