Waterborne Infectious Diseases Associated with Exposure to Tropical Cyclonic Storms, United States, 1996–2018

[Announcer] This program is presented by the Centers for Disease Control and Prevention.

[Sarah Gregory] Hello, I'm Sarah Gregory, and today I'm talking with Dr. Victoria Lynch, a postdoctoral researcher at Columbia University Mailman School of Public Health in New York. We'll be discussing waterborne diseases associated with tropical storms in the United States.

Welcome, Dr. Lynch.

[Victoria Lynch] Thank you so much for having me. I really appreciate it.

[Sarah Gregory] Let's start off with what is stormwater?

[Victoria Lynch] Sure. So stormwater is the runoff that flows over land and impervious surfaces (like roadways or parking lots) after intense rain or snowmelt events, and it is generated when this water accumulates faster than it can be absorbed into the ground or contained in storm drain systems.

[Sarah Gregory] Is it different than floodwater?

[Victoria Lynch] Not really. Essentially, they are synonyms. Technically, floodwater can accumulate unrelated to a storm event. So I'd say stormwater falls in the category of floodwater, but floods can occur via numerous events. And so, it doesn't have to be a storm to generate floodwater.

[Sarah Gregory] Ah, gotcha. What kind of pathogens can end up in stormwater? Just generally...I know we're going to talk about specifics a little later.

[Victoria Lynch] Sure. Well, if you picture flooding in any environment—rural, urban—or any type of floods—river floods, flash floods—pathogens in those flooded environments can be suspended and mobilized by the floodwater or the stormwater (specifically looking at storms). So the kinds of pathogens that end up in stormwater really depend on the environment. The two main categories are pathogens that are natural inhabitants of the environment and those that are not. So for that first category (natural inhabitants), their presence is not necessarily a sign of contamination, but they can be mobilized by stormwater and then present at higher levels in water that people interact with. But they do naturally inhabit and live in a range of water sources.

The second category is pathogens that are not natural inhabitants of the water, and therefore their presence is an indication of contamination. And broadly, these pathogens are found in human sewage, livestock waste, or wildlife waste. So any pathogen that can infect those people, livestock, wildlife, can end up in stormwater.

[Sarah Gregory] So are these pathogens that can make people really sick?

[Victoria Lynch] The short answer is yes. The severity depends on age and the underlying health status of people who become infected. But for most people, these infections are relatively mild.

They cause gastrointestinal symptoms (like nausea, vomiting, diarrhea) that are manageable—it's quite unpleasant and disruptive. For people who are older or immunocompromised, they can be very serious and potentially life-threatening if they lead to disseminated infection. For very young children—really, children under the age of five—two pathogens in particular can be very serious—that's *E. coli* and *Cryptosporidium*. And we can talk about those specific pathogens a bit more later, but *E. coli* can lead to hemolytic uremic syndrome, which is a serious kidney disease that can be life-threatening. And repeated *Cryptosporidium* infections in young children, particularly those that are malnourished, can lead to stunted growth. So while again, the vast majority of cases are mild and unpleasant, there can be very serious cases among older, very young, and immunocompromised people. I will also note here that Legionnaires' disease (caused by the *Legionella* bacteria) is its own case separate from I just discussed. These are primarily opportunistic infections that are very serious, have a high mortality rate, and infect people who are immunocompromised or elderly.

[Sarah Gregory] So you mentioned the two different kinds of pathogens in the storm water—so the unnatural ones (the sewage and that sort of thing). How do they get in the water in the first place?

[Victoria Lynch] Most of the paths for these pathogens that are not natural inhabitants of the water, they can enter bodies of water that we use for drinking water, irrigation, recreation, via contamination events. I like to think of it as three primary routes of contamination. The first are combined sewer overflows or sewage bypasses, and this happens when as the result of stormwater rushing and inundating systems it overwhelms the sewer and is discharged directly into receiving waters, and those are waters that we can use for recreation and potentially for drinking water. And this occurs in typically older systems where sanitary sewers—so that that comes from our homes and apartments and offices—ends up in the same pipe as stormwater drains. And when, again, when these are inundated, that combination of both stormwater and sanitary sewage from our homes ends up directly discharged without treatment.

The next primary route would be flooding near farms. In agricultural areas, there's often...animal waste is often stored in these slurry facilities, and those can be left open. And when flooding occurs, the floodwater (the stormwater) can interact with slurry or just animal waste that's present on farmlands, mobilize both of those pathogens, and contaminate nearby water. And I'll note there that that can be of particular concern if the water that is contaminated is then used to irrigate crops.

And then finally, contamination can occur just in the natural environment. If you have wildlife that has infectious diseases (it's very common that they do), then if their waste is present in the natural environment and a storm occurs and that stormwater is mobilizing pathogens in the environment, that will just be deposited into lakes, rivers, streams, other bodies of water in the natural environment.

[Sarah Gregory] Okay. So how do people end up getting sick from this contaminated stormwater? Are they drinking it, like people swimming and sucking it in? What's happening here?

[Victoria Lynch] Yes, that is one very important route. And I want to note here that most of the work on stormwater and waterborne disease is observational and relies on our understanding of likely transmission pathways. To rigorously establish causal pathways, we would need much more detailed water quality and epidemiological data that would enable us to determine specific sources of contamination and infection. So when I speak about this, I'm building on what we know about pathogen biology, sources of contamination, and flood dynamics. So I just want to have that as a disclaimer that a lot of my research and research in this field is based on plausible explanations of what we know, but we are really missing a lot of granular water quality and epidemiological data. So just with all of that said, the likely routes of exposure are contaminated drinking water, exposure in natural water used for recreation, and potentially direct exposure to stormwater after major floods.

[Sarah Gregory] How long can these pathogens stay in water sources after a storm?

[Victoria Lynch] That varies by pathogen. So the pathogens that are natural inhabitants of the environment, they are always present in water sources. So as I noted before, a storm may affect their concentration. For the other pathogens that enter the water sources as a result of contamination events, they can persist for a few days up to, in some cases, 18 months.

[Sarah Gregory] Wow, 18 months. It would be really hard to track it back then, right?

[Victoria Lynch] Yes. It poses a real challenge for, as I said earlier, kind of establishing these really clear causal pathways.

[Sarah Gregory] You mentioned a minute ago drinking water. Wouldn't typical water treatment get rid of these pathogens out of our drinking water?

[Victoria Lynch] Yes. And I should say that...I'll start by saying that with effective monitoring and treatment, almost any amount of contamination can be addressed. But here we need to look at a few exceptions or places not where effective treatment fails. So starting with drinking water, it does depend on your source. So many people rely on private wells for drinking water, and those are not regulated, and so it's on the property owner to ensure that their well is not contaminated with pathogens that could cause waterborne disease.

The other source that we want to focus on is groundwater. And so, many community water systems in the United States use groundwater instead of surface water for their drinking water source. For decades, groundwater drinking water sources were thought to be protected from most contamination, and so they weren't regulated or regularly monitored. And it was only in 2006 that EPA introduced the groundwater rule. So now, groundwater sources are supposed to be regularly monitored and treated if necessary. But...I don't want to step too far outside of my area of expertise, but there is evidence that compliance and testing is not always enforced and that many, particularly smaller community water systems that use groundwater, are not in compliance. Especially in rural areas that rely on groundwater as a drinking water source, there can be issues with (or struggles with) compliance as a result of limited material resources and personnel. So those are two areas where drinking water is either not regulated because it's a private well or is supposed to be regulated but there may be some challenges to accomplishing that.

The other important source of contamination could be from wastewater treatment. And as I noted above that when there are major storms and flood events, that stormwater can inundate sanitation infrastructure and lead to the direct discharge of wastewater into the environment. And while we are not typically drinking that untreated water, we can come into contact with it through recreation or just being proximate to floodwater.

[Sarah Gregory] Understanding that long-term, granular studies have been done on tracking this, do we know how big a problem this is in the United States?

[Victoria Lynch] The short answer here, again, is that we really don't know. Most cases of these infections are never captured by the healthcare system and water quality analyses—especially pathogen-specific analyses—are rarely conducted period, much less after storm events, which is what we would need to determine the extent to which specific storms are driving contamination, and therefore, transmission. I should note though that there is a 2021 estimate published in *Emerging Infectious Diseases* and led by Sarah Collier that estimated that there were about 7.15 million waterborne illnesses annually in the United States. Now, most of these were mild ear infections, things like that. But I thought the value of that piece was that there is likely a tremendous burden of waterborne disease that we are largely unaware of.

Taking a step back in terms of how big of a problem is this, what we do know is that the United States...in most places in the United States, we have deteriorating, aging drinking water and wastewater infrastructure. And we also know that as a result of increasing atmospheric temperature and climate change, we are at risk for more serious or severe storm events. And so, while we don't know a lot about the specific burden of disease, I think we do know that from an infrastructure standpoint and then a vulnerability to extreme storms, we know that those are likely big and increasing challenges in the US.

[Sarah Gregory] One more thing to add to the Halloween list.

Are there areas where this is more of a concern—you talked about wells and that kind of thing—say, rural versus urban? Or does it matter anymore?

[Victoria Lynch] Yes, it definitely matters. So most places in the US experience severe storms—if not tropical cyclones, other types of severe storms—and many places are susceptible to flooding. I do think, however, that rural communities are most vulnerable due to overlapping risk factors. Many people in rural areas, as you noted, rely on private wells for drinking water or on community water systems that use groundwater, and I described some of those risks earlier. These areas often also include agricultural regions where floodwater can mobilize animal waste and contaminate water that's used for drinking water or for recreation.

And finally, rural populations are in general, in the US, aging. And older people are at risk for these infections. They're more susceptible to serious outcomes that I described earlier. So this is not to diminish the risk faced by urban populations, particularly given that damage to a single urban water treatment facility can affect hundreds of thousands of people—so in no way diminishing that serious risk. I do see this as a particularly important issue for rural health and rural populations.

[Sarah Gregory] So we've been discussing more storms and the likelihood of greater storms in the future. What about just individual stronger storms? Are they more likely to transmit pathogens to people?

[Victoria Lynch] So this isn't the most satisfying answer, but maybe. And I think that really depends on how we define 'strong'. So a storm can have really dangerous wind speeds but not necessarily bring a tremendous amount of rain, or it can have lower wind speeds but move more slowly and lead to extensive rainfall accumulation and flooding. And depending on the type of storm, we may have different risks for the people affected—so for example, a storm with really high wind that is known well in advance may lead to evacuation. And so, the area may be at great risk, but if people have largely evacuated, their individual risk actually is reduced. So individual behavior is an important factor there.

Conversely, a storm that has high wind and destroys the local wastewater treatment plant may not have a tremendous amount of flooding, but if wastewater treatment isn't effective, then we could have more contaminated water entering the environment. And so, one of the motivations for the study published in EID was to try to gain some insight into how storm types might influence the transmission of these pathogens. But the short answer is that there could be some counterintuitive associations here depending on whether the storm is bringing strong wind, rain, or both, and then how people react to that information.

[Sarah Gregory] What time period did you cover in your study and why did you choose those years?

[Victoria Lynch] Our study period is 1996 to 2018. That includes 23 storm seasons. And in the Atlantic storm basin, the storm season is June through November. So we restricted our study to those months of the year. We used this time period because we had access to detailed data on storm characteristics for all of the storms that made landfall (named storms that made landfall) during that time period. And by detailed data, I mean county-level data on wind speed, gust duration, daily and cumulative rainfall, and distance from the storm track.

[Sarah Gregory] So take a minute here to tell us about your study. What were you looking for?

[Victoria Lynch] Sure. The primary objective was to see if there was an association between tropical cyclonic storms and six waterborne or partially waterborne pathogens. To do this, we needed to define exposure to these storms, which isn't always straightforward, as they can be characterized by several variables that are often not well correlated. So as I just described, storms can have high wind speeds but not necessarily bring heavy rain. To account for this, we used three storm exposure variables—total rainfall, maximum sustained wind speeds, and distance from the storm track—to assess the association with cases of these waterborne pathogens.

The second objective was that we wanted to see if, given an association, it varies by storm type. And again, by that I mean storms with high wind and high rain or high wind but low rain, and so on. And we think that these pathogen-specific analyses are really important because in the absence of really granular, excellent water quality data, the type of pathogen may provide insight into sources of contamination that could inform future research.

[Sarah Gregory] What pathogens did you specifically look at for your study, then?

[Victoria Lynch] So I'll start with the pathogens that primarily cause gastrointestinal disease, and they are the parasites *Cryptosporidium* and *Giardia* and the enteric bacteria *Salmonella*, *Shigella*, and Shiga toxin-producing *E. coli*. And then the last pathogen is different from those others (it causes respiratory infection), and that's *Legionella*—the bacteria *Legionella* that causes Legionnaires' disease. And this is the only one that is a natural inhabitant of the environment. Those first five that cause gastrointestinal disease, those are all not natural inhabitants of the environment, and so they're introduced during contamination events.

[Sarah Gregory] And Legionnaires' is the most deadly, I think you mentioned earlier.

[Victoria Lynch] Yes. By far, Legionnaires' disease has a very high mortality rate with serious infection that primarily occurs among people who are elderly and/or immunocompromised.

[Sarah Gregory] And Legionnaires' disease was discovered by the founder of the *Emerging Infectious Diseases* journal, Joe McDade. Did you know that?

[Victoria Lynch] I didn't know that, but that's very exciting to hear. Legionnaires' was a particular focus in my doctoral research. So I have, I wouldn't say an obsession for it, but I'm particularly interested in its association with environmental factors.

[Sarah Gregory] Yes, we're very proud of him.

Okay, so *Salmonella* and *E. coli* are, as you said, foodborne bacteria. How do they get in the stormwater?

[Victoria Lynch] Recognize earlier I said waterborne and partially waterborne.
With *Salmonella* and *E. coli* in particular, as well as with *Shigella*, it is important to note that most cases are foodborne. But—and this is part of my argument and work—that it is important to identify how storms and flooding could influence their transmission, even as it relates to foodborne outbreaks or cases. So both of these pathogens colonize livestock—namely poultry and pigs—and they could get into stormwater via flooding on farmland. This is a particular concern with storms and flooding near concentrated animal feeding operations that house thousands and thousands of animals at one time, and therefore generate tremendous amounts of waste that could carry these bacteria. While, again, most cases are foodborne, they can certainly enter the environment when flooding occurs near CAFOs or other farms.

The other way that they could enter the environment is if people are infected and the bacteria are present in their waste. If that waste enters sewage systems and if we have inundating floodwaters (stormwaters), those bacteria can enter the environment via combined sewer overflows or those bypasses that I described earlier.

[Sarah Gregory] You talked about the data sources a minute ago. Tell us more specifically about what kind of data you used and how you collected it.

[Victoria Lynch] I'll start by saying that I benefitted from the incredible work of thousands of other people to conduct this study. So the surveillance case data came from CDC's National Notifiable Disease Surveillance System dataset, and this is publicly available, though it was in an unwieldy format for this type of research. The data consists of lab-confirmed cases from hospitals, emergency department visits, and primary care visits that are reported to local health departments and then compiled by state health departments for submission to CDC. So I really...I benefit from the incredible work of local and state health department officials for access to the case data.

The storm data came from the excellent hurricane exposure dataset compiled by Brooke Anderson at Colorado State. She and her team used gridded rainfall data and National Hurricane Center data to provide county-level estimates of storm exposure for all main tropical cyclonic storms that made landfall in the US from 1998 to 2018. So again, I'm benefitting from really extraordinary work by other research groups.

[Sarah Gregory] How long did you work on this study before you published it?

[Victoria Lynch] I worked on this study for 13 months before I published it. And a lot of that, I should note, it was a project from my dissertation research, so it wasn't the sole focus for those 13 months. But the CDC dataset is excellent, but it isn't designed for this type of research. So converting it into a format that we could use in statistical models did take a lot of time and I am—hoping to having done it, I certainly don't want anyone else to have to do it—I am actually working on turning that into a data package that will be available for anyone interested in it.

[Sarah Gregory] Oh, interesting. That was going to be my next question, is it going to be made available? Well, that's terrific.

[Victoria Lynch] I'm working on it as we speak. I'm excited to save anyone else the time.

[Sarah Gregory] Well, it's very public service-minded of you, and we appreciate it. And frankly, I think that's an enormous amount of wading through things in a mere 13 months and writing your article.

What did you find after all of this work?

[Victoria Lynch] Well, thank you. The quick summary is that there was an association between exposure to storms for some of the pathogens but not all of the pathogens that I have described. And more specifically, we found that for the Shiga toxin-producing *E. coli* infections, there was a 48 percent increase in case rates one week after storm events that was elevated for the second week after storm events and then returned to baseline.

For Legionnaires' disease, we found a 42 percent increase in case rates two weeks after the storm. And then for *Cryptosporidium*, we found a 52 percent increase in case rates during the storm week that then climbed over the ensuing weeks. For the other pathogens, we found that there was largely no association with storm events with the exception of *Shigella*, there was actually a slight decrease in case rates during the week of the storm.

[Sarah Gregory] Didn't you find that storm-related rainfall had no effect on *Salmonella?*

[Victoria Lynch] Correct. We found that there was no association between exposure to storm-related rainfall or wind with the case rate for *Salmonella*. And this was, again, in the absence of really granular data I want to be careful about kind of overstepping what we know from this study, but one plausible explanation for this could be that *Salmonella* is largely foodborne. And as a result, storms genuinely do not drive transmission—that there may be some transmission related to exposure to storms and flooding, but that it is really (no pun intended) drowned out relative to the dominant mode of transmission, which is foodborne transmission.

The other...related to that, is that there are so many foodborne outbreaks during these summer months that even if there is a signal, it might be hard to identify given that we actually don't have that many storm waves. And so, when we're just comparing weeks where a storm occurred to those without a storm, relatively we don't have that many. And so, there might...and we have a number of foodborne outbreaks kind of as the background transmission, we might not be able to identify peaks associated with storm exposure. So it could be that there is genuinely no association, or it could be that we just don't at this point have the data to identify an association.

[Sarah Gregory] I see. So you've mentioned many challenges in putting this all together. Is there a particular challenge that you faced during this study that you would like to mention?

[Victoria Lynch] I noted that it was time consuming to kind of wrangle the data into a usable format, although I think that that's part of one's doctoral training. But I wouldn't say that was a challenge, although it was time consuming. The biggest challenge was reconciling the fact that these data aren't designed for resolved epidemiological studies. And so, for example, with the case data, that's reported at a state level. So for each week, we know how many cases were reported to the NNDS's dataset in that month but not at each county, much less each zip code. And so, having to figure out how to rigorously account for the fact that the epidemiological data are at a state level when our storm exposure is obviously highly local, that was probably the biggest methodological challenge. Though I am proud of how we accounted for that and included sensitivity analyses in the study design itself.

[Sarah Gregory] And you mentioned that you plan to make your data available for everyone to use in the future. How would you like to see it used?

[Victoria Lynch] Thank you, I love this question. First, from a research and policy lens, I would really like to see an increased focus on drinking and wastewater infrastructure as I think this is an incredibly important component of preparing for the effects of climate change and storm severity, in particular. I also think that this study demonstrates the importance of pathogen-specific water quality data, and so I hope that this serves as an impetus for research universities, but also local health departments and departments of environment protection at the city/county/state level, whatever the structure is in a given region, that it serves as an impetus for conducting epidemiological and water quality studies, particularly after storm events.

I would also like to see this work motivate further focus on rural areas and rural communities. I do think that the vulnerability to infectious diseases in general and certainly exposure to contaminated water, severe storm events, is an issue of environmental justice. And that people who often have the fewest resources, whether they are elderly or immunocompromised or in rural areas, often have the fewest resources to respond and recover from storm events. And so, I hope that this serves as a jumping off point, as many, many people are studying this, but I hope it contributes to a renewed focus on storms and infectious diseases as an issue of environmental justice.

From an individual point of view, I think that if you are someone who has a private well for drinking water, I would really encourage you to get it tested regularly and especially after a storm with extensive flooding. So in terms of research and science you can use, I hope that that's a take-home message. And in the extent that one has control over it, there are things that people can do in their homes and neighborhoods to prepare for floodwater, whether that's through planting or small changes to urban design, that is something that people can be involved in directly on their own property or get involved in their local community government to advocate for that.

[Sarah Gregory] Well then, in addition to that, using your research, what future research do you think other people need to do (or you yourself)?

[Victoria Lynch] At this point, I might sound a bit like a broken record, but I think the first steps would be to implement even pilot projects to conduct epidemiological surveillance after major flooding and storm events and compare that with stormwater quality analyses, again, after storm events. And ideally, we would have that data for the entire US, but I think it's a pretty big challenge. And if health departments at city/county/state level have the means to conduct pilot projects now, particularly in vulnerable areas like the southeast that experiences these really devastating cyclonic storms, I think that would be an excellent use of local health department and department of environmental protection research funds. So that would be the kind of first step that I think is really important.

[Sarah Gregory] Well Dr. Lynch, tell us about your job and what made you interested in studying storms and diseases.

[Victoria Lynch] Sure. Now I'm a postdoctoral environmental epidemiologist at Columbia, which is also where I completed my PhD, so I didn't stray too far. My doctoral research focused on how climate affects or can be associated with waterborne diseases, and now as a postdoc, I'm expanding beyond just waterborne diseases to look more broadly at how extreme climactic events like storms, heatwaves, potentially wildfires are associated with a broader range of health outcomes. Although, I will always have a particular interest in waterborne disease.

And in terms of why I developed this as my focus, I think that extreme events can force reckoning in a way that slow-moving environmental events unfortunately don't. I think they can generate interest and activism and a research focus that motivates change, and I think they also can lay bare some of the weaknesses in either our infrastructure, our public health infrastructure, our research focus and particularly can reveal inequity in those areas. So again, not to in any way diminish the very important work of looking at daily temperature or daily rainfall or continuous environmental changes, I do think that extreme events and storms have played a unique and critical role in setting research and policy agenda. And that's why I have, up until this point, focused on extreme events, and in particular, tropical cyclonic storms.

[Sarah Gregory] Well, considering how things have been lately—floods, fires, earthquakes, tornadoes, hurricanes in abundance—I think you're going to have your work cut out for you in the next few years. And it sounds like it's going to be an exciting time, too.

[Victoria Lynch] Thank you. I wish it weren't. I frequently say that I wish that this research wasn't necessary. But given that it is, I feel very, very lucky that I get to engage with it every single day and feel a bit more empowered instead of just seeing the incredible amount of uncertainty and instability in our climate and feeling like I have no agency. So I would say it's a huge privilege to be able to work on this, with the obvious caveat that I wish it weren't necessary.

[Sarah Gregory] Well, yes. I think we can all agree with that.

So in the weeds here as opposed to big, major events like you're looking at, is there a certain pathogen that worries you the most?

[Victoria Lynch] Yes. So Legionnaires' disease has by far the highest mortality rate of all the pathogens we've discussed, and is therefore the most concerning. Its incidence has increased dramatically in the United States in the last 20 years. Now, that is likely due in part to greater awareness about Legionnaires' and more people are being properly diagnosed (tested and diagnosed). But that aside, the combination of it—increasing incidence and high mortality rate—and the fact that it really affects people who are immunocompromised, particularly with respiratory infections, we do live in a country with an aging population and after the last three years, a greater proportion of people are...do have now respiratory conditions as a result of COVID-19 pandemic. So I think the combination of its incidence, its high mortality rate, and then just the increasing number of people who might be susceptible in the first place, that's a single pathogen that I am most worried about.

The other way that I would interpret this question is looking a bit more at a population level. And as I've noted several times now, I am very concerned about populations that are vulnerable...in rural areas that are vulnerable to both contamination events and then the infectious diseases themselves. And in those populations, *E. coli* and *Cryptosporidium* can be very, very serious infections among elderly or immunocompromised people. And so, from a population health standpoint, I am most concerned about older, rural populations.

[Sarah Gregory] Well, on that note, I want to thank you for taking the time to talk with me today, Dr. Lynch. I think you're probably a very busy person.

[Victoria Lynch] Thank you so much. I really appreciate your taking the time and your interest in this work. It definitely serves as a motivator for me.

[Sarah Gregory] And thanks for joining me out there. You can read the August 2023 article, Waterborne Infectious Diseases Associated with Exposure to Tropical Cyclonic Storms, United States, 1996–2018, online at cdc.gov/eid.

I'm Sarah Gregory for *Emerging Infectious Diseases*.

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