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Climate change, extreme events, and increased risk of salmonellosis: foodborne diseases active surveillance network (FoodNet), 2004-2014

Michele E. Morgado^{1†}, Chengsheng Jiang^{1†}, Jordan Zambrana¹, Crystal Romeo Upperman^{1,2}, Clifford Mitchell³, Michelle Boyle³, Amy R. Sapkota^{1†} and Amir Sapkota^{1*†} 

Abstract

Background: Infections with nontyphoidal *Salmonella* cause an estimated 19,336 hospitalizations each year in the United States. Sources of infection can vary by state and include animal and plant-based foods, as well as environmental reservoirs. Several studies have recognized the importance of increased ambient temperature and precipitation in the spread and persistence of *Salmonella* in soil and food. However, the impact of extreme weather events on *Salmonella* infection rates among the most prevalent serovars, has not been fully evaluated across distinct U.S. regions.

Methods: To address this knowledge gap, we obtained *Salmonella* case data for *S. Enteritidis*, *S. Typhimurium*, *S. Newport*, and *S. Javiana* (2004-2014; n = 32,951) from the Foodborne Diseases Active Surveillance Network (FoodNet), and weather data from the National Climatic Data Center (1960-2014). Extreme heat and precipitation events for the study period (2004-2014) were identified using location and calendar day specific 95th percentile thresholds derived using a 30-year baseline (1960-1989). Negative binomial generalized estimating equations were used to evaluate the association between exposure to extreme events and salmonellosis rates.

Results: We observed that extreme heat exposure was associated with increased rates of infection with *S. Newport* in Maryland (Incidence Rate Ratio (IRR): 1.07, 95% Confidence Interval (CI): 1.01, 1.14), and Tennessee (IRR: 1.06, 95% CI: 1.04, 1.09), both FoodNet sites with high densities of animal feeding operations (e.g., broiler chickens and cattle). Extreme precipitation events were also associated with increased rates of *S. Javiana* infections, by 22% in Connecticut (IRR: 1.22, 95% CI: 1.10, 1.35) and by 5% in Georgia (IRR: 1.05, 95% CI: 1.01, 1.08), respectively. In addition, there was an 11% (IRR: 1.11, 95% CI: 1.04-1.18) increased rate of *S. Newport* infections in Maryland associated with extreme precipitation events.

*Correspondence: amirsap@umd.edu

[†]Michele E. Morgado and Chengsheng Jiang these authors contributed equally.

[†]Amy R. Sapkota and Amir Sapkota these authors contributed equally.

¹ Maryland Institute for Applied Environmental Health, University of Maryland School of Public Health, 2234F SPH Building #255, College Park, MD 20742, USA

Full list of author information is available at the end of the article



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Conclusions: Overall, our study suggests a stronger association between extreme precipitation events, compared to extreme heat, and salmonellosis across multiple U.S. regions. In addition, the rates of infection with *Salmonella* serovars that persist in environmental or plant-based reservoirs, such as *S. Javiana* and *S. Newport*, appear to be of particular significance regarding increased heat and rainfall events.

Keywords: *Salmonella*, Foodborne illness, Climate change, Extreme heat, Extreme precipitation

Introduction

There are an estimated 9.4 million cases of foodborne illness each year in the United States [1]. Nontyphoidal *Salmonella* spp. is a leading cause of U.S. foodborne illnesses, resulting in 19,336 hospitalizations and an estimated 378 deaths each year [1]. Infections with nontyphoidal *Salmonella* are frequently associated with contaminated poultry, meat products, eggs, and fresh produce [2–5]; however, animal sources of contamination can be markedly different by state [6]. Symptoms of *Salmonella* infection, or salmonellosis, can manifest from 12 to 72 hours after exposure and are characterized by an acute onset of fever, diarrhea, and abdominal cramps [7]. Gastrointestinal illness caused by *Salmonella* usually self resolves within a few days, but vulnerable populations (e.g., children under 5 years old, elderly persons, and immunocompromised patients) are more likely to develop severe complications such as bacteremia [7, 8].

There are over 2,500 recognized *Salmonella enterica* serovars [9] and each one contains a different variation of cell-surface carbohydrates and flagellar proteins, known as O and H antigens [10]. These serovars may dominate a wide range of ecological niches and can also exhibit varying degrees of virulence [11]. The *S. enterica* serovars Enteritidis and Typhimurium are responsible for most of the salmonellosis cases across the globe, most likely due to their high rates of infection in chickens [10]. Currently, the serovars *S. Enteritidis*, *S. Typhimurium*, *S. Newport*, and *S. Javiana* account for over 50% of the fully serotyped isolates characterized in the U.S. [5].

Several recent studies have observed an association between food and waterborne disease occurrence and increased ambient temperature and precipitation [12–22]. This is of particular importance given that current increasing trends in the frequency, intensity and duration of extreme heat and precipitation events are projected to grow in response to climate change [23]. These changes have the potential to exacerbate bacterial proliferation, as well as soil and water contamination, and present an added challenge to the prevention of foodborne illness [24]. The increased spread and persistence of *Salmonella* spp. associated with extreme weather events is especially concerning in food commodities that are often eaten raw, such as fruits and vegetables [24, 25].

A recent study by our group demonstrated the impact of extreme temperature and precipitation events on the risk of *Salmonella* infection in the State of Maryland [16]. We described a 4.1% and a 5.6% increase in salmonellosis risk associated with a 1-unit increase in extreme temperature and precipitation events, respectively [16]. This risk was more pronounced in coastal versus non-coastal areas; however, our findings were limited to the State of Maryland. The present study builds upon our previous work, evaluating the impact of extreme temperature and precipitation events on the risk of salmonellosis with the four most common serovars (*S. Enteritidis*, *S. Typhimurium*, *S. Newport*, and *S. Javiana*) across multiple U.S. regions.

Methods

Data sources

Salmonella case data were obtained from the Foodborne Diseases Active Surveillance Network (FoodNet), a collaboration between the Centers for Disease Control and Prevention (CDC), 10 state health departments, the US Department of Agriculture's Food Safety and Inspection Service (USDA-FSIS), and the US Food and Drug Administration (FDA). FoodNet sites are located throughout the country and include ten states that represent roughly 15% of the total U.S. population. These FoodNet sites conduct active, population-based surveillance on laboratory-confirmed infections that are caused by nine pathogens commonly transmitted through food, including *Salmonella*. For this study, we limited our analyses to culture-confirmed *Salmonella* cases from the seven FoodNet sites with active surveillance across all counties (Connecticut, Georgia, Maryland, Minnesota, New Mexico, Oregon, and Tennessee). In addition, we restricted the analyses to reported cases of the following four predominant *Salmonella* serovars between 2004 and 2014: Enteritidis, Javiana, Newport, and Typhimurium. We defined a case as an individual whose biological specimen (stool, blood, or other) was culture confirmed for the presence of *Salmonella*, regardless of symptoms or date of onset.

We obtained age, sex, and race/ethnicity data from the 2010 Census of Population and Housing, Summary File 1 and poverty data from the American Community Survey 2006–2010 [26]. These data were downloaded at the county level from the Census website and used to

calculate county level percentages of 1) people in the age groups <5, 5-17, 18-64, and ≥ 65 ; 2) individuals living below the poverty level in 2010; 3) populations of individual races; and 4) males and females. Concentrated animal feeding operation data were obtained from the 2007 U.S. Census of Agriculture, National Agriculture Statistics Service [27].

Coastal county definition

Counties were classified as coastal or non-coastal based on National Oceanic and Atmospheric Administration (NOAA) definitions outlined in its coastal assessment framework [28]. Specifically, NOAA defines a county as a coastal county if: “1) at least 15% of the county’s total land area is located within a coastal watershed, or 2) a portion of or an entire county accounts for at least 15% of a coastal U.S. Geological Survey 8-digit cataloging unit” [28].

Weather data and extreme heat/precipitation events

We obtained daily weather data from the National Climatic Data Center website for the 1960-2014 period, including daily maximum temperature (TMAX) and precipitation (PRCP) [29]. Details regarding identification of extreme heat and precipitation events have been described previously [16, 30]. In brief, we used daily TMAX and PRCP for the 1960-1989 period to compute calendar day and location (county) specific 95th percentile thresholds for TMAX and PRCP, which are referred to as Extreme Temperature Threshold 95th percentile (ETT₉₅) and Extreme Precipitation Threshold 95th percentile (EPT₉₅), respectively. Daily PRCP and TMAX values during the study period for which we have the FoodNet data (2004-2014) were compared to their respective calendar day and location specific 95th percentile thresholds and assigned a value of “1” if they exceeded the thresholds, and “0” otherwise. Days exceeding the TMAX thresholds were identified as extreme heat events and those exceeding the PRCP thresholds were identified as extreme precipitation events. The rationale behind the use of extreme events as exposure metric instead of continuous temperature/precipitation is their relevance in the context of climate change and existing literature linking weather variables with salmonellosis.

Statistical model

We used negative binomial Generalized Estimating Equations (GEE) [31, 32] to investigate the relationship between exposure (monthly count of extreme weather events) and outcome (monthly count of salmonellosis cases) to account for overdispersion and repeated nature of outcome measure. First, we ran an overall analysis, adjusting for potential confounders including poverty

status, age, sex, and race. We then performed stratified analyses by race (Non-Hispanic White, Non-Hispanic Black), degree of urbanization (urban, suburban, rural), density of broiler chicken operations (high, moderate, low), and geographic location (coastal counties, non-coastal counties). The PROC GENMOD command with REPEATED statement was used for controlling the autocorrelation of repeated measurements within each county. All statistical analyses were performed using SAS 9.4 (Cary, NC USA).

Results

Between 2004 and 2014, 32,951 cases of culture-confirmed *Salmonella* infection from serovars Enteritidis, Javiana, Newport, and Typhimurium were reported to FoodNet by Connecticut, Georgia, Maryland, Minnesota, New Mexico, Oregon, and Tennessee (Table 1).

Among the 7 FoodNet sites analyzed, most *S. Enteritidis* (5.5 per 10,000), *S. Javiana* (8.6), *S. Newport* (8.6) and *S. Typhimurium* (10.4) cases occurred among those aged 0-4 years old (Table 1). Salmonellosis cases across all serovars were similarly distributed between males and females but showed some variability among race/ethnicity groups, with the highest observed cases per 10,000 in Non-Hispanic Black populations (2.7) for *S. Enteritidis* (Table 1). *Salmonella* cases for all serovars, *S. Enteritidis* (3.3), *S. Javiana* (3.3), *S. Newport* (3.8), and *S. Typhimurium* (2.8), were more frequently reported in counties with higher poverty rates (Table 1). In terms of other characteristics, salmonellosis cases were reported more frequently in rural settings for most serovars, except for *S. Enteritidis* (2.8 per 10,000 in urban), and mostly in low-density broiler chicken operation areas (Table 1).

The average incidence of salmonellosis (across all reported serovars) among all seven FoodNet sites was highest in Georgia (23.4 cases per 100,000 population) and lowest in Oregon (10.0 cases per 100,000 population) (Fig. 1). New Mexico had the second highest average incidence of salmonellosis (16.0 cases per 100,000 population), while the remainder of the states averaged roughly 13.8 cases per 100,000 population (Fig. 1).

Extreme heat and precipitation related risk of salmonellosis varied considerably between FoodNet sites and across serovars (Fig. 2). For instance, extreme heat exposure was associated with a statistically significant increased risk of infection with *S. Newport* in two out of seven FoodNet sites (Tennessee and Maryland) (Fig. 2A). In Tennessee, we observed a 6% increase in risk of *S. Newport* infections (Incidence Rate Ratio (IRR): 1.06, 95% Confidence Interval (CI): 1.04-1.09) and in Maryland we observed a 7% increase in risk (IRR: 1.07, 95% CI: 1.01-1.14). Meanwhile, significant but less robust increases in the risk of *S. Newport* infections were

Table 1 Characteristics of FoodNet reported cases of *Salmonella* serovar Enteritidis, Javiana, Newport, and Typhimurium by the states of Connecticut, Georgia, Maryland, Minnesota, New Mexico, Oregon, and Tennessee between 2004-2014

Characteristic	% Population	Salmonella serovar (# cases, # cases per 10,000)			
		Enteritidis	Javiana	Newport	Typhimurium
Age					
0 to 4	6.5	1510 (5.5)	2391 (8.6)	2378 (8.6)	2877 (10.4)
5 to 17	17.5	1678 (2.3)	967 (1.3)	973 (1.3)	1866 (2.5)
18 to 64	63.3	6281 (2.3)	1860 (0.7)	3094 (1.1)	3412 (1.3)
≥ 65	12.6	1167 (2.2)	587 (1.1)	1002 (1.9)	871 (1.6)
Unreported	NA	17	4	6	10
Gender					
Female	51.0	5531 (2.5)	2970 (1.4)	3899 (1.8)	4353 (2.0)
Male	49.0	5098 (2.4)	2823 (1.4)	3534 (1.7)	4668 (2.2)
Unreported	NA	24	16	20	15
Race/Ethnicity					
Non-Hispanic Black	17.4	1965 (2.7)	787 (1.1)	701 (0.9)	1363 (1.8)
Non-Hispanic White	66.0	5324 (1.9)	2784 (1.0)	3977 (1.4)	4407 (1.6)
Hispanic	10.2	678 (1.6)	366 (0.8)	484 (1.1)	903 (2.1)
Other	6.4	319 (1.2)	87 (0.3)	174 (0.6)	311 (1.1)
Unreported	NA	2367	1785	2117	2052
% Poverty					
High	17.4	2421 (3.3)	2468 (3.3)	2807 (3.8)	2102 (2.8)
Median	35.1	2884 (1.9)	1766 (1.2)	2256 (1.5)	3071 (2.1)
Low	47.4	5348 (2.7)	1575 (0.8)	2390 (1.2)	3863 (1.9)
Urbanization					
Rural	15.6	1537 (2.3)	1714 (2.6)	2095 (3.2)	2005 (3.0)
Suburb	30.2	2768 (2.2)	2533 (2.0)	2669 (2.1)	2769 (2.2)
Urban	54.2	6348 (2.8)	1562 (0.7)	2689 (1.2)	4262 (1.8)
Broiler Chicken Operations					
High	32.5	3145 (2.3)	624 (0.5)	1235 (0.9)	2743 (2.0)
Moderate	37.2	3864 (2.4)	2416 (1.5)	3137 (2.0)	3347 (2.1)
Low	30.3	3644 (2.8)	2769 (2.1)	3081 (2.4)	2946 (2.3)
Region					
Coastal	33.7	4822 (3.4)	2078 (1.4)	2395 (1.7)	2599 (1.8)
Non-Coastal	66.3	5831 (2.1)	3731 (1.3)	5058 (1.8)	6437 (2.3)

observed in Georgia (IRR: 1.03, 95% CI: 1.00-1.05) and New Mexico (IRR: 1.03, 95% CI: 1.00-1.07) (Fig 2A).

Extreme precipitation events increased the risk of *S. Javiana* by 22% in Connecticut (IRR: 1.22, 95% CI: 1.10-1.35) and by 5% (IRR: 1.05, 95% CI: 1.01-1.08) in Georgia, while the increase in risk was borderline significant in Maryland (IRR: 1.09, 95% CI: 0.99-1.19) (Fig 2B). Similarly, extreme precipitation events were associated with an 11% increase in the risk of *S. Newport* (IRR: 1.11, 95% CI: 1.04-1.18) in Maryland, and a 7% increase in the risk of *S. Enteritidis* in New Mexico (IRR: 1.07, 95% CI: 1.02-1.11). In Oregon, extreme precipitation was associated with increased rates of *S. Typhimurium* infections (IRR: 1.05, 95% CI: 1.01-1.10) and *S. Enteritidis* infections,

although the latter was only borderline significant (IRR: 1.07, 95% CI: 1.00-1.14) (Fig 2B).

We performed stratified analyses to examine whether the association between salmonellosis risk and extreme temperature and precipitation events varied by density of broiler chicken operations, geographic location, race, and urbanization level (Fig 3). Extreme heat related salmonellosis risks were significant in urban counties (IRR: 1.02, 95% CI: 1.01-1.04) and counties with moderate to high density of broiler chicken operations (Fig. 3A). By comparison, extreme precipitation events increased salmonellosis incidence in both coastal and non-coastal counties, as well as urban and suburban locations, but not in rural areas. We also observed higher extreme

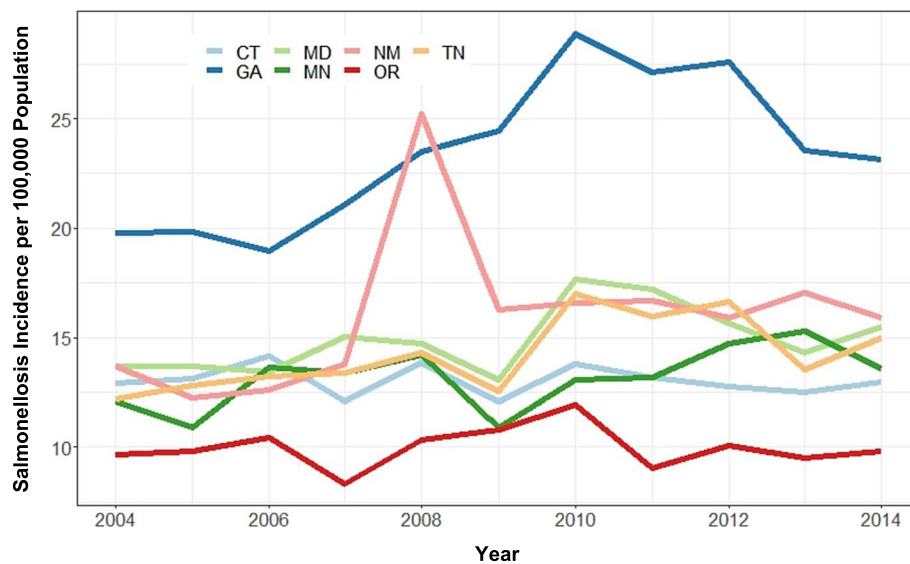


Fig. 1 Incidence of Salmonella infection per 100,000 population for all serovars by year and by state during 2004-2014. The FoodNet sites are Connecticut (CT); Maryland (MD); New Mexico (NM); Tennessee (TN); Georgia (GA); Minnesota (MN); and Oregon (OR)

precipitation-related salmonellosis risks among non-Hispanic Blacks (IRR: 1.04, 95% CI: 1.02-1.06) compared to non-Hispanic Whites (IRR: 1.01, 95% CI: 0.98-1.04) (Fig. 3B).

Discussion

Several studies have observed that the prevalence of *Salmonella* infections is strongly influenced by changes in ambient temperature [12, 18, 22, 33–38], with higher rates often observed during the summer [12, 22, 39]. Multiple studies have also provided evidence that salmonellosis rates are positively associated with increased rainfall events [19, 22, 33, 40]. Moreover, there is growing evidence suggesting projected changes to climate [23] will affect the incidence of foodborne illness, including *Salmonella* infections [12, 16, 18, 24, 25, 41]. Our findings provide further evidence that increases in ambient temperature and precipitation levels, particularly in the form of extreme events, are associated with increases in rates of salmonellosis. Additionally, our results show that the response to this association is not uniform across different regions in the U.S., or among the four most prevalent *Salmonella* serovars.

The heterogeneity in this relationship is exemplified by *S. Newport*, which was associated with extreme heat events in 4 out of 7 FoodNet sites (Georgia, Maryland, New Mexico, and Tennessee), whereas higher extreme precipitation related risks for all four serovars were observed across a greater number of FoodNet sites. *Salmonella* infections can be serovar-specific and have been shown to differ geographically [42, 43], across age and

gender [42], among race/ethnicity groups and by poverty levels [43, 44]. In addition, sources of infection and routes of transmission can vary among *Salmonella* serovars [4]. Previous studies have also found that *Salmonella* serovars may respond differently to extreme heat events [45] and that serovars with environmental reservoirs (such as *S. Javiana*) may be more heavily impacted by increased precipitation [19, 46]. The uneven response that we observed among the four serovars (*S. Enteritidis*, *S. Javiana*, *S. Newport*, and *S. Typhimurium*) regarding extreme heat and precipitation events, suggests that environmental reservoirs and exposure pathways for *Salmonella* infection may be of increased relevance.

The elevated rate of infection with *S. Newport* in Georgia, New Mexico, Tennessee, and Maryland associated with extreme heat exposure could reflect the serovar's ability to contaminate a wide range of food commodities, especially fresh produce and dairy or beef cattle [4, 47], which represent diverse foods commonly grown in these states [27]. In addition, *S. Newport* has been shown to persist and survive in elevated temperatures inside fresh produce crops such as tomatoes [48]. These states are especially characterized by high densities of broiler chicken operations (Georgia and Maryland), and a greater presence of cattle (Tennessee) and dairy (New Mexico) operations in rural areas [27]. Previous works have documented occupational exposures to *Salmonella* spp. among workers in livestock operations [42, 48, 49], as well as the sustained proliferation of *Salmonella* in the environment when using untreated waste from animal agriculture [50, 51]. Animal waste can contaminate

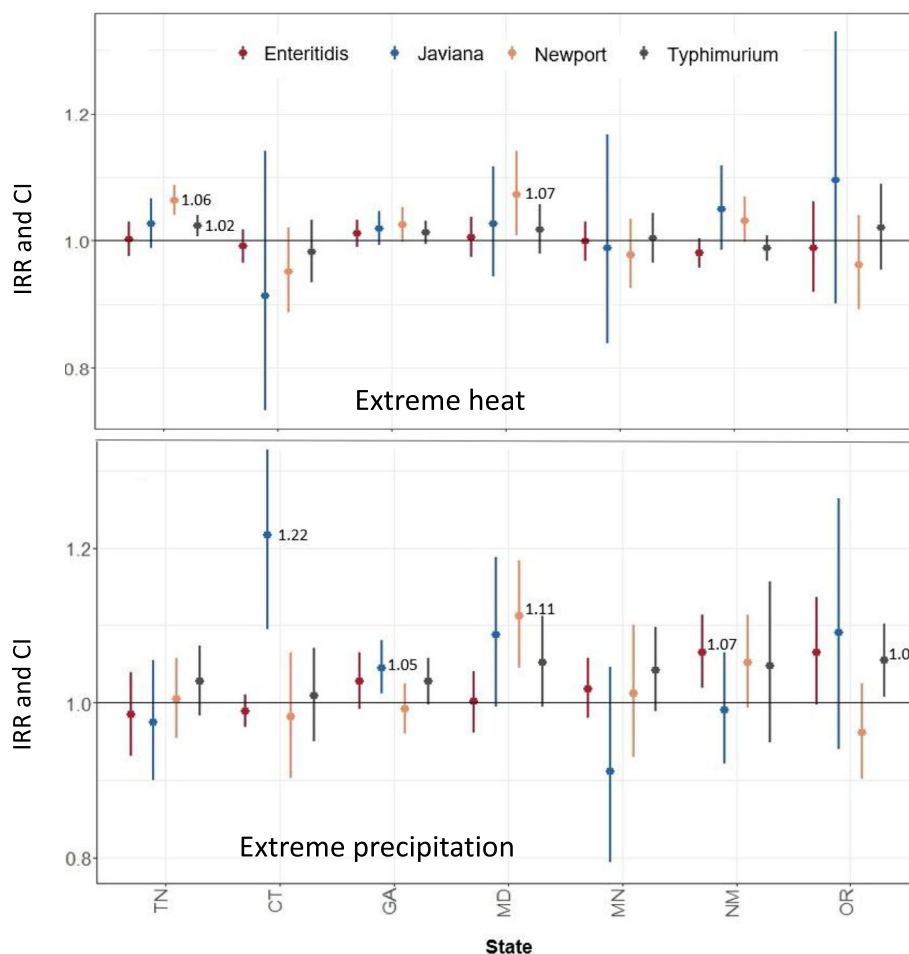


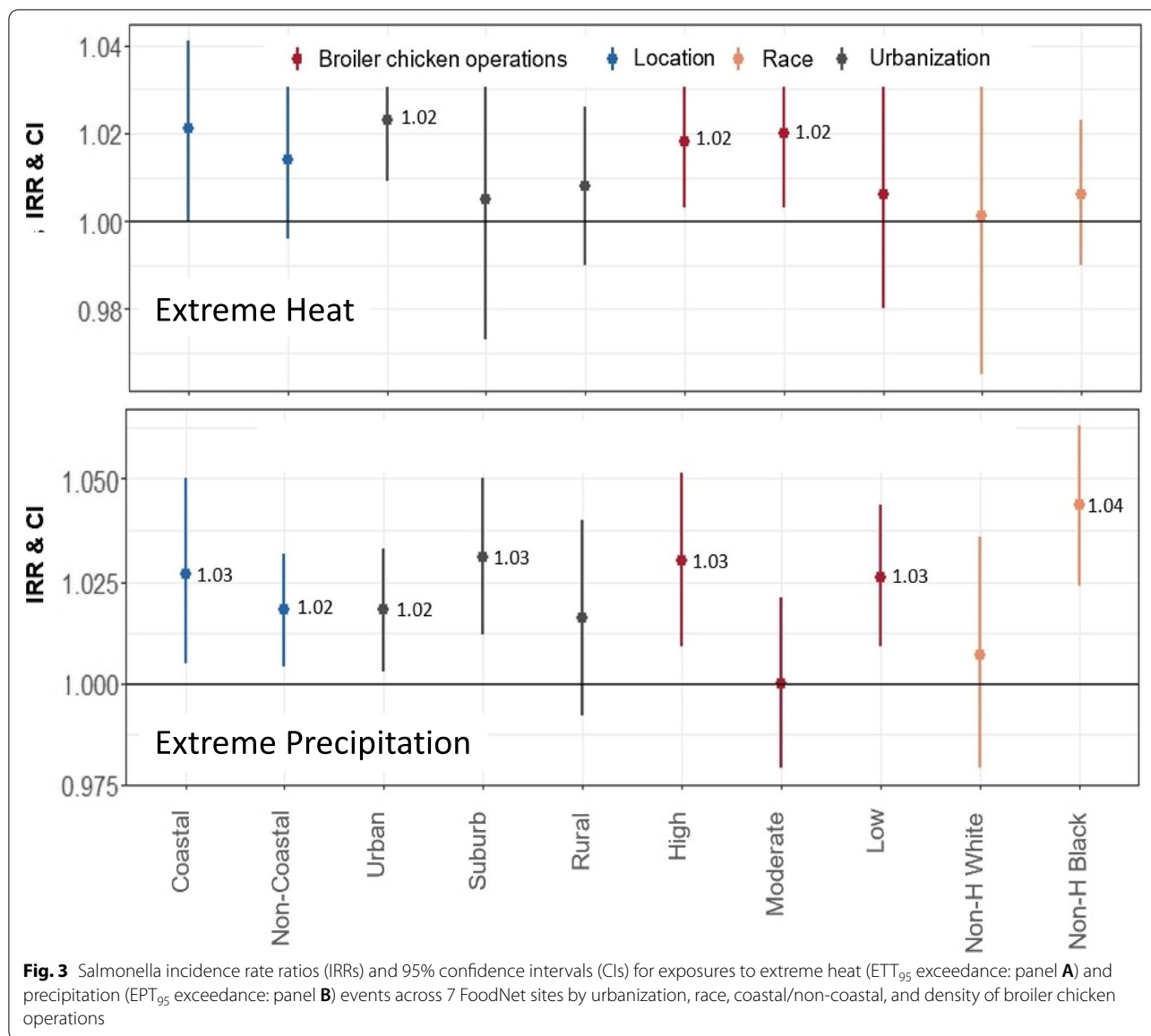
Fig. 2 Salmonella incidence rate ratios (IRRs) and 95% confidence intervals (CIs) for exposures to extreme temperature (ETT₉₅ exceedance: panel A) and precipitation (EPT₉₅ exceedance: panel B) events across 7 FoodNet sites by serovar (Enteritidis, Javiana, Newport, and Typhimurium)

soil, surface waters and groundwater through runoff and has been shown to be a source of *Salmonella* [51]. In addition, studies have pointed to the persistence of *S. Newport* isolates in irrigation water and soil in the Mid-Atlantic region, which may act as long-term reservoirs of contamination [52, 53]. Moreover, it has been observed that *Salmonella* internalization within fresh produce might be more pronounced with extreme weather conditions, including drought from sustained periods of heat [54]. There are also concerns of increased dissemination of pathogens such as *Salmonella* from grazing cattle as elevated temperatures may cause them to harbor and shed bacteria at higher levels [24, 55, 56].

Extreme precipitation events can increase the frequency of human contact with contaminated water sources [57–60], and they can also increase the likelihood of fresh produce coming into contact with contaminated runoff [24, 61, 62]. This can be especially important for the dissemination and persistence of *Salmonella* serovars

with natural reservoirs, such as *S. Javiana* [4, 19, 46, 63], as well as those frequently associated with plant-derived food commodities, such as *S. Newport* [4]. In our study we observed a significant increase in the risk of *S. Javiana* infections in the states of Connecticut and Georgia, as well as an elevated risk of *S. Newport* in Maryland, associated with extreme precipitation events.

Previous studies have shown the importance of environmental and wild animal reservoirs, particularly amphibians and reptiles, in explaining the greater distribution of *S. Javiana* infections in the southeastern U.S. [46, 63, 64]. Correspondingly, a positive association was found between *S. Javiana* infections and the percentage of wetland coverage in Georgia, which provides a habitat for many amphibian species [65]. In addition, Lee et al. [19] observed that the infection risk of *S. Javiana* increased in the coastal plain region in Georgia, following periods of extreme rainfall. This region is characterized by extensive agricultural production, where fresh



produce and livestock may overlap, as well as a large percentage of aging wells and septic systems [19]. These conditions can increase the risk of human exposure to contaminated water sources, either through the consumption of contaminated produce and drinking water, or with recreational use [22, 33, 54, 57, 63]. In contrast, the northeastern state of Connecticut reported less *S. Javiana* infections than Georgia during our study period, but the risk of infection associated with extreme rainfall events was far more pronounced. Wetland coverage is considerably diminished in Connecticut [66] and agricultural production covers the smallest area of the included states [67]; however, approximately 23% of its population are served by private well systems [68] compared

to the national estimated average of 13% [69]. This could underscore the importance of private well contamination following periods of excessive rainfall, as well as the persistence of *Salmonella* serovars, such as *S. Javiana* in the soil and water [53, 70, 71].

S. Newport has also been found to survive for extensive periods of time in soil and water [53, 70], particularly in moist organic soil [71] which is prevalent in Maryland [72]. Studies have found that both extreme heat and precipitation can lead to an increased prevalence of *Salmonella* in crops such as lettuce, either through internalization or transfer of pathogens with contaminated surface waters [54]. As noted earlier, the elevated risk of *S. Newport* in Maryland associated with both extreme

heat and precipitation events could reflect its continued persistence and ability to disseminate over land and contaminate crops [52, 53]. Additionally, recreational water activities and drinking from contaminated private wells may be an important route of human exposure following periods of heavy rainfall [12, 19, 33, 63].

Overall, our study indicated a stronger association between extreme precipitation events and salmonellosis across the U.S., compared to extreme heat events. Previous works have described the role of excessive rainfall in the proliferation of *Salmonella* in the soil, water, and a range of food commodities [12, 19, 61, 62, 70, 73]. Furthermore, the elevated risk of *Salmonella* infection associated with poultry and livestock reservoirs, as observed with *S. Typhimurium* and *S. Enteritidis* [4], may be of special consideration even in states without large animal production facilities, such as Oregon and New Mexico [67]. Potential gastrointestinal disease vectors could include rodent populations [74], which have been shown to increase in semi-arid regions like New Mexico following periods of wetness [75]. Wild birds can also be infected with *Salmonella*, particularly *S. Typhimurium*, representing a potential risk of contamination to local waterways and increased human exposure [49].

The wide geographic area (7 states) covered in this study, along with the rich dataset of county-specific heat and precipitation events and *Salmonella* cases used to develop the exposure and outcome metrics, are key strengths of this study. A unique aspect of our study is the analysis of differences in incidence with respect to several major *Salmonella* serovars (*S. Enteritidis*, *S. Javiana*, *S. Newport* and *S. Typhimurium*). The wide range of serovar responses to the extreme events across the FoodNet sites highlights the important role that state and local public health departments must play in the response to nationally identified associations. Given the large toll that salmonellosis takes on public health and the exacerbating impacts of climate change on its incidence, it is important that public health adaptation measures take these issues under consideration.

Limitations of this study are that the data were aggregated at the county level which does not consider other factors that might influence observed associations between serovar incidence rates and specific locations. We also focused on the daily exceedance of the thresholds of precipitation and temperature and did not assess the magnitude of the exceedance itself. Furthermore, we relied on the date of a culture positive test to ascertain relevant exposure, rather than the date of symptom onset or potential infection, which were not available. Likewise, we did not have information related to specific outbreaks that might have contributed to the temporal clustering of the cases. It is also important to note that while FoodNet

is an active surveillance system, the data are an imperfect measure of the true incidence of foodborne illness. Reported cases of laboratory confirmed salmonellosis can often understate the true incidence of infections due to underreporting and underdiagnosis, and the data may represent some of the most severe cases.

Conclusions

Our findings indicate that the association between salmonellosis incidence and extreme weather events is heterogeneous among the four most common *Salmonella* serovars, and across multiple U.S. regions. Moreover, the elevated rates of infections with *S.* serovars that dominate in natural or plant-based reservoirs (e.g., *S. Javiana*, and *S. Newport*) associated with extreme heat and rainfall events, merits special attention. These findings emphasize the need for public health related decisions to be crafted at the state and local levels to meet each region's changing environmental and climatic conditions.

Abbreviations

CDC: Centers for Disease Control and Prevention; CI: Confidence Interval; FDA: US Food and Drug Administration; FoodNet: Foodborne Diseases Active Surveillance Network; IRR: Incidence Rate Ratio; NOAA: National Oceanic and Atmospheric Administration; PRCP: daily maximum precipitation; TMAX: daily maximum temperature; U.S.: The United States; USDA-FSIS: US Department of Agriculture's Food Safety.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12940-021-00787-y>.

Additional file 1: Supplemental Table 1: *Salmonella* Cases by Season (2004-2014).

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Authors' contributions

MM: Investigation, Data interpretation, Writing- Original draft preparation, Writing- Reviewing and Editing, Visualization. CJ: Methodology, Software, Formal Analysis, Investigation, Data Curation. JZ: Data Interpretation, Writing- Original draft preparation. CRU: Investigation, Resources, Writing- Reviewing and Editing. CM: Investigation, Resources, Writing- Reviewing and Editing. MB: Investigation, Resources, Writing- Reviewing and Editing. ARS: Conceptualization, Writing- Reviewing and Editing, Supervision, Project Administration, and Funding Acquisition. AS: Conceptualization, Methodology, Writing- Reviewing and Editing, Supervision, Project Administration, and Funding Acquisition. All authors read and approved the final manuscript.

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Availability of data and materials

The data that support the findings of this study are available from the Centers for Disease Control and Prevention (CDC), but restrictions apply to the availability of these data, which are not publicly available. Data are however available from the authors upon reasonable request and with permission of the CDC.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

None

Author details

¹Maryland Institute for Applied Environmental Health, University of Maryland School of Public Health, 2234F SPH Building #255, College Park, MD 20742, USA. ²Aclima, Inc., San Francisco, CA, USA. ³Maryland Department of Health, Prevention and Health Promotion Administration, Baltimore, MD, USA.

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