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April 19, 2022

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Date

Enteric Disease Incidence in Georgia Following Extreme Rain and Drought Events

By

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Degree to be Awarded: Master of Science in Public Health

Environmental Health-Epidemiology

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Bachelor of Science
University of Georgia
2020

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An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Science in Public Health
in Environmental Health-Epidemiology
2022

Abstract

Enteric Disease Incidence in Georgia Following Extreme Rain and Drought Events

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Background The Georgia Department of Public Health participates in the Foodborne Diseases Active Surveillance Network (FoodNet) and conducts surveillance for nine enteric pathogens, four of which may have environmental routes of transmission. Current evidence suggests that extreme precipitation events may be associated with an increased incidence of enteric diseases. Current climate trends suggest an increase in the frequency and intensity of extreme precipitation events in coming decades due to climate change which could translate to an increase in enteric pathogen incidence. However, current literature lacks evidence for all enteric pathogens and tends to focus on salmonellosis incidence. To address this gap, we assessed the association between precipitation conditions and enteric disease incidence across four pathogens: *Salmonella, Campylobacter, Cryptosporidium,* and Shiga-Toxin Producing *E. coli* (STEC)

Methods Associations between precipitation and enteric disease incidence were estimated via Poisson regression models. Salmonellosis, campylobacteriosis, cryptosporidiosis, and STEC cases (N = 71,691) reported to the Georgia Department of Public Health between 2000 – 2019 for patients that did not travel internationally and were not linked to a known outbreak were included in analysis. Precipitation was defined for the conditions during the week of disease onset (7 days prior to onset date) and antecedent conditions (8-weeks prior to disease onset date, lagged by one week). Models controlled for time via season and year of disease onset and a county and year-specific population offset was used to account for population variation.

Results When examining precipitation data, a significant increase in disease incidence was observed among days with wet antecedent conditions and extreme, wet, and dry precipitation conditions the week of disease onset compared to days for which the antecedent and week of onset precipitation conditions were both classified as dry. The most notable increase occurred among days with wet antecedent conditions and dry week of precipitation conditions (IRR = 1.11, 95% CI: 1.08, 1.13). Days with wet antecedent and extreme or wet week of precipitation conditions also produced significant increases in enteric disease incidence (IRR = 1.04, 95% CI: 1.02, 1.07; IRR = 1.04, 95% CI: 1.01, 1.07). Days with dry antecedent conditions and wet week of precipitation conditions led to a significant decrease in enteric disease incidence (IRR = 0.96, 95% CI: 0.94, 0.99) as compared to days with both antecedent and week of precipitation conditions that were classified as dry. Disease-specific models showed similar trends with less precise confidence intervals due to smaller sample sizes.

Discussion This study suggests that antecedent precipitation conditions have a considerable influence on enteric disease incidence. The most notable increase in disease incidence occurs when there is a period characterized by high precipitation (wet antecedent conditions) followed by a brief dry period (dry week of precipitation) indicating there may be a combination of behavioral and environmental bacterial factors at play. The findings suggest there may be an increase in enteric disease incidence due to increased extreme weather-related events due to climate change.

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Acknowledgements

Foremost, I would like to express my deepest gratitude to Hope Dishman from the Georgia Department of Public Health, without whom this project would not have been possible. Thank you for your dedicated support and patience throughout this entire process and for always lending thoughtful insight into this study. I cannot express enough how thankful I am for all of the time and effort you have invested into myself and this project.

I would also like to thank Lana Jones and the epidemiology team at the Georgia Department of Public Health's FoodNet site. Thank you for your continuous support of this endeavor.

I would also like to extend my greatest thanks to my thesis advisor Dr. Stefanie Ebelt. Thank you for your analytical expertise and orienting this project on the right path.

Finally, I would like to thank my friends and family for their endless love and support throughout my entire academic career. Your encouragement has allowed me to continue to reach my goals and I could not be more thankful for each of you.

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Introduction

The Georgia Department of Public Health conducts active enteric disease surveillance on nine food and waterborne pathogens via the Foodborne Diseases Active Surveillance Network (FoodNet), as one of ten FoodNet sites funded by the Centers for Disease Control and Prevention *(Emerging Infections Program (EIP), n.d.)*. Of the five pathogens with the highest incident cases per year, four (*Cryptosporidium*, *Campylobacter*, *Salmonella*, and Shiga-toxin producing *E. coli* (STEC)) may have an environmental route of transmission via contaminated water exposure or exposure to infected animals (CDC, 2018).

There are over 5,000 reported cases of enteric disease associated with the pathogens surveilled by FoodNet in Georgia annually, although the actual number of infections is likely higher. Most cases are reported in summer months that are associated with increased temperatures, increased precipitation, and more frequent recreational water use (CDC, 2018). *Salmonella* is consistently the most common infection identified by Georgia FoodNet surveillance, and has been found in multiple environmental studies throughout Georgia, including in soil and surface water environmental samples (Cann et al., 2013; Harris et al., 2018; Lee et al., 2019). Bacterial replication and transmission to surface water is amplified by increased temperature and precipitation, leading to increased infections in seasons characterized by these conditions. The link between extreme weather-related events and an increased frequency of enteric diseases leaves cause for concern as such events are expected to increase in both frequency and intensity in the coming decades due to climate change (Jiang et al., 2015). Previous literature has indicated an increased risk of salmonellosis incidence following periods of extreme precipitation in Georgia (Lee et al., 2019), however, there has been little investigation of other enteric pathogens with environmental routes of transmission.

Methods

Precipitation Data

Precipitation data was sourced from the 1,355 monitoring sites in the state of Georgia from the National Centers for Environmental Information: National Oceanic and Atmospheric Association (NOAA). The geographic location of each station was translated from longitude and latitude to their associated county within the state of Georgia, and all stations within the same county were averaged to give distinct values for the average temperature and precipitation level within the county on each date from 2000 Jan 1 – 2019 Dec 31. Data was collected for 155 out of 159 counties in Georgia, the remaining counties (Chattahoochee, Hancock, Jenkins, and Taliaferro) were excluded from analysis as they included only 211 cases, less than 0.01% of total case counts over the 20-year study period.

Health and Demographic Data

Health and demographic data were queried from the Georgia Department of Public Health, a FoodNet site, for reported cryptosporidiosis, salmonellosis, campylobacteriosis, and STEC cases from 2000 Jan 1 – 2019 Dec 31. Lab-confirmed cases of each disease were required to be reported to the Georgia Department of Public Health by state law. County and state of residence of cases were reported and those that were found to have a residence outside of the state of Georgia or that were known to have traveled internationally in the week prior to disease onset (or 15 days prior in the case of cryptosporidiosis cases) were excluded from analysis. Cases linked to a known outbreak were also excluded from analysis as their cause was definitively determined. In total 71,691 cases were eligible to be included in analysis. Due to missing precipitation data in a few counties, 64,329 cases were included in the final analysis across 155 counties in Georgia.

The race, ethnicity, age at diagnosis, and gender of cases were included in the data from the Georgia Department of Public Health. The races included in this data set were American Indian/Alaska Native, Asian, Black/African American, Hawaiian/Pacific Islander, Multiracial, or White. The ethnicities included in this data set were Hispanic or non-Hispanic. This information was used to describe the overall study population.

Statistical Analysis

We analyzed a 20-year data set with cases aggregated by county of residence and date of onset of illness. We used Poisson regression models with county-specific intercepts to estimate the association between county-level daily enteric disease case counts and precipitation conditions. Precipitation conditions were defined categorically for both the precipitation the week of disease onset and the precipitation during antecedent weeks. Specifically, precipitation conditions during the week of disease onset were defined using the sum of the county-level precipitation for the 7 days prior to the date of disease onset and categorized as *extreme* if they fell at or above the 90th percentile of rolling 7-day sums across the 20-year period, *wet* if they fell at or above the mean of the rolling 7-day sums across the 20-year period, and *dry* if they fell below the mean of the rolling 7-day sums across the 20-year period. Antecedent precipitation conditions were defined using the sum of the precipitation in the 8 weeks prior to disease onset, lagged by one week as to not include the precipitation conditions from the week of disease onset (as defined as its own exposure variable). The 8-week antecedent conditions were categorized as *wet* if they fell at or above the mean of the rolling 56-day sums across the 20-year period and *dry* if they fell below the mean of the rolling 56-day sums across the 20-year period.

First to estimate the association between only precipitation in the week of disease onset and case count incidence, we modeled:

$$\log E\left(COUNT_{ij}\right) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, SEASON_{ij} + \beta_4 YEAR_{ij} + \beta_5\, SEASON_{ij} * YEAR_{ij} + \log(POPULATION), \quad (1)$$

where $COUNT_{ij}$ refers to the enteric disease case count in county *i* on day *j*. *WKEXT* is a county-specific dichotomous variable that refers to whether the precipitation the week of disease onset was classified as *extreme*. *WKWET* is a county-specific dichotomous variable that refers to whether the precipitation the week of disease onset was classified as *wet*. We controlled for time by controlling for *SEASON* using a 4-level categorical variable as categorized by the Northern Hemisphere meteorological seasons (winter, spring, summer, autumn) and *YEAR* of date of onset. *Winter* was categorized as December, January, and February, *Spring* was categorized as March, April, and May, *Summer* was categorized as June, July, and August, and *Autumn* was categorized as September, October, and November. A county and year-specific offset for *POPULATION* was included to account for varying county populations.

Next, we estimated the association between only antecedent precipitation conditions and case incidence via the following model:

$$\log E\left(COUNT_{ij}\right) \sim \alpha + \beta_1 ANTWET_{ij} + \beta_2\, SEASON_{ij} + \beta_3 YEAR_{ij} + \beta_4\, SEASON_{ij} * YEAR_{ij} + \log(POPULATION), \quad (2)$$

where all variables are defined the same as in model 1 and *ANTWET* is a county-specific dichotomous variable that refers to whether the antecedent precipitation conditions were defined as *wet*.

We then estimated the interaction between the week of and antecedent precipitation conditions and their association with case incidence using the following model:

$$\log E(COUNT_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3 ANTWET_{ij} + \beta_4 SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6 SEASON_{ij} * YEAR_{ij} + \beta_7 WKEXT_{ij} * ANTWET_{ij} + \beta_8 WKWET_{ij} * ANTWET_{ij} + \log(POPULATION), \quad (3)$$

where all variables are defined as in models 1-2.

Finally, disease-specific models were considered to estimate the association between case incidence of each illness with the interaction of week of precipitation and their antecedent conditions:

$$\log E(SALM_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3 ANTWET_{ij} + \beta_4 SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6 SEASON_{ij} * YEAR_{ij} + \beta_7 WKEXT_{ij} * ANTWET_{ij} + \beta_8 WKWET_{ij} * ANTWET_{ij} + \log(POPULATION), \quad (4)$$

where all the variables are defined as in models 1-3 and *SALM* refers to case counts of salmonellosis.

$$\log E(CAMPY_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3 ANTWET_{ij} + \beta_4 SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6 SEASON_{ij} * YEAR_{ij} + \beta_7 WKEXT_{ij} * ANTWET_{ij} + \beta_8 WKWET_{ij} * ANTWET_{ij} + \log(POPULATION), \quad (5)$$

where all the variables are defined as in models 1-4 and *CAMPY* refers to case counts of campylobacteriosis.

$$\log E(STEC_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3 ANTWET_{ij} + \beta_4 SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6 SEASON_{ij} * YEAR_{ij} + \beta_7 WKEXT_{ij} * ANTWET_{ij} + \beta_8 WKWET_{ij} * ANTWET_{ij} + \log(POPULATION), \quad (6)$$

where all the variables are defined as in models 1-5 and *STEC* refers to case counts of STEC.

$$\log E(CRYPTO_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, ANTWET_{ij} + \beta_4\, SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6\, SEASON_{ij} * YEAR_{ij} + \beta_7\, WKEXT_{ij} * ANTWET_{ij} + \beta_8\, WKWET_{ij} * ANTWET_{ij} + \log(POPULATION), \qquad (7)$$

where all the variables are defined as in models 1-6 and *CRYPTO* refers to case counts of cryptosporidiosis.

Sensitivity Analyses

We ran sensitivity analyses controlling for month of onset rather than season of onset which returned results of the same trends that were less precise than controlling for seasonality. We also ran models for which the antecedent conditions were defined as the sum of the precipitation from the four weeks prior to the date of onset, lagged by one week as to not reiterate the exposure to precipitation the week of onset as encapsulated by the sum of the 7 days prior to onset of illness. Changing the definition of the antecedent conditions still showed the same trend in disease incidence rate. There were significant increases among days with wet antecedent conditions and extreme or dry precipitation the week of disease onset. There were also significant decreases in disease incidence rate among days with dry antecedent conditions and extreme or wet precipitation the week of disease onset compared to days for which the antecedent conditions and precipitation the week of disease onset were both classified as dry. Finally, we ran models exploring the association of the precipitation the week of onset and disease incidence controlling for time, stratified by antecedent conditions. The results seen were as expected where among cases with wet antecedent conditions, days with extreme or wet precipitation the week of disease onset led to a significant decrease in disease incidence rate. Among cases with dry antecedent conditions, days for which precipitation the week of disease onset was classified as wet showed a significant decrease in disease incidence rate. Days with extreme precipitation the week of disease onset also exhibited a decrease in disease incidence rate on average, however it was not significant.

Results

The mean county-level annual enteric disease incidence rate over the 20-year study period ranged from 16.34 cases per 100,000 people to 145.08 cases per 100,000 people, with an overall average enteric disease incidence rate of 47.29 cases per 100,000 people. The majority of enteric disease cases occurred in non-Hispanic persons in Georgia (91.0% of the 70.2% of cases with known ethnicity) as opposed to those of Hispanic ethnicity during the 20-year period. Those who identified as white, non-Hispanic made up nearly half (45.3%) of reported cases in the 20-year period. Males (51.1%) and females (48.3%) both made up nearly half of reported enteric disease cases from 2000 – 2019. The case demographics are consistent with the demographics of the entire population of Georgia. There was a noteworthy number of pediatric enteric disease cases during the 20-year period, with 25% of reported cases being in those under the age of two.

Salmonellosis was the most common enteric disease that occurred between 2000 and 2019, accounting for 45,544 (63.5%) of reported enteric disease cases. Campylobacteriosis was the next most frequent cause of enteric disease, being responsible for 17,181 (24.0%) of reported enteric disease cases in Georgia. Cryptosporidiosis and STEC accounted for 5430 (7.6%) and 3536 (4.9%) of enteric disease cases, respectively. Case counts steadily increased from less than 2,500 cases annually in 2000 to nearly 5,000 cases in 2019 (Figure 4).

Days for which the 7 days prior were classified as wet had an enteric disease incidence rate that was 4% lower (IRR = 0.96, 95% CI: 0.95, 0.98) than days for which the 7 days prior were classified as dry (Model 1, Table 3). Days for which the 8 weeks prior to the week of onset were classified as wet had an enteric incidence rate that was 8% higher (IRR = 1.08, 95% CI: 1.06, 1.10) than days for which the 8 weeks prior were classified as dry (Model 2, Table 3).

While controlling for season and year of disease onset, days for which the 8-week antecedent conditions were classified as wet had an enteric disease incidence rate that was consistently higher than days for which both the 8-week antecedent conditions and the week of precipitation were classified as dry as shown by Model 3 (Table 4). In each case, the reference group was classified as days for which the 8-week antecedent conditions and the precipitation the week of disease onset were classified as dry. The most notable increase was among days for which the antecedent conditions were wet and the precipitation the week of disease onset was classified as dry with an average increase of 11% (IRR = 1.11, 95% CI: 1.08, 1.13). There were also significant increases on days with wet antecedent conditions for which the precipitation the week of disease onset was classified as wet or extreme, both exhibiting an average increase of 4% (IRR = 1.04, 95% CI: 1.02, 1.07; IRR = 1.04, 95% CI: 1.01, 1.07) as compared to the reference. Days with dry antecedent conditions and for which the precipitation the week of disease onset was classified as wet had an enteric disease incidence rate that was on average 4% less (IRR = 0.96, 95% CI: 0.94, 0.99) as compared to days for which the antecedent conditions and precipitation the week of disease onset were both classified as dry.

While controlling for season and year of disease onset and only considering salmonellosis cases, similar trends were observed as shown by Model 4 (Table 4). The reference group was defined as days for which the 8-week antecedent conditions and the precipitation the week of disease onset were classified as dry. Days with wet antecedent conditions for which the precipitation the week of disease onset was classified as wet had an average salmonellosis incidence rate increase of 6% (IRR = 1.06, 95% CI: 1.02, 1.09) while those days for which the precipitation the week of disease onset were classified as dry had an average salmonellosis incidence rate increase of 13% (IRR = 1.13, 95% CI: 1.10, 1.16) compared to the reference. However, days with dry antecedent conditions and precipitation the week of disease onset classified as wet, had a salmonellosis incidence rate was on average 4% lower (IRR = 0.96, 95% CI: 0.93, 0.99) than days for which the antecedent conditions and precipitation the week of disease onset were both classified as dry.

While controlling for season and year of disease onset and only considering campylobacteriosis cases, similar trends were seen in which days for which the 8-week antecedent conditions were wet had an average increase in incidence rate; however, the strongest association was seen among days for which the week of disease onset was classified as extreme and the smallest increase was observed for days for which the precipitation the week of onset was classified as dry. Model 5 (Table 4) also had a reference group defined as days for which the 8-week antecedent conditions and the precipitation the week of disease onset were both classified as dry. Days with precipitation the week of onset defined as extreme had an average campylobacteriosis disease incidence rate increase of 17% (IRR = 1.17, 95% CI: 1.09, 1.26) compared to the reference. There was an average increase in campylobacteriosis incidence rate of 11% (IRR = 1.11, 95% CI: 1.06, 1.17) and 10% (IRR = 1.10, 95% CI: 1.05, 1.16) when the precipitation the week of disease onset was classified as wet and dry, respectively, when those days had wet antecedent conditions. No significant difference was observed among days with dry antecedent conditions.

While controlling for season and year of disease onset and only considering STEC cases, the most prominent association was observed between days with dry antecedent conditions for which the precipitation the week of disease onset was classified as wet, with an average decrease in STEC incidence rate of 15% (IRR = 0.85, 95% CI: 0.76, 0.95) compared to days for which the 8-week antecedent conditions and the precipitation the week of disease onset were both classified as dry (Model 6, Table 4).

While controlling for season and year of disease onset and only considering cryptosporidiosis cases, again a similar trend was seen for which the most notable increase in cryptosporidiosis incidence rate occurred on days with wet antecedent conditions and the precipitation the week of disease onset classified as dry compared to days for which the 8-week antecedent conditions and precipitation the week of disease onset were both classified as dry, exhibiting an average increase of 10% (IRR = 1.10, 95% CI: 1.02, 1.20) (Model 7, Table 4).

Discussion

In this analysis, we estimated the association between precipitation and enteric disease incidence across a 20-year span for 155 of 159 counties in Georgia (due to weather data availability constraints). We explored how the temporal relationship between precipitation and disease onset modified the overall association by accounting for both the precipitation the week of disease onset and the 8-week antecedent conditions and accounting for the interaction of these conditions.

Counties in south Georgia had the largest disease incidence rates (Figure 1). The Suwannee River Basin is located in these counties and previous studies have detected both *E. coli* and *Salmonella* in environmental samples from this watershed. This watershed allows for ideal conditions for enteric pathogens to thrive in the environment, especially after long periods of high precipitation that could lead to flooding events or opportunities for surface water transmission of enteric pathogens. Counties in north Georgia had the largest number of days for which the precipitation the week of disease onset was classified as extreme or wet (Figure 2). Counties in north Georgia also had the largest number of days with wet antecedent conditions (Figure 3). The overall average annual precipitation varied widely from year-to-year throughout the 20-year study period and did not appear to be linearly related to the increase in case counts over the 20-year period (Figure 4).

We found that antecedent conditions appeared to play a larger role in driving the case incidence than the week-of precipitation conditions. Wet antecedent conditions led to increased enteric disease incidence across all counties, with the strongest association occurring when the precipitation the week of onset was classified as dry. This association is strongly driven by salmonellosis cases as they made up over half of all enteric disease cases reported to the Georgia Department of Public Health from 2000 – 2019. Disease-specific associations were less precise than overall associations due to smaller sample sizes, however they all showed similar trends for which wet 8-week antecedent conditions led to an increase in disease incidence rate and dry 8-week antecedent conditions with wet or extreme precipitation the week of disease onset led to a decrease in disease incidence rate.

Enteric disease pathogens thrive in environments with ample access to water, so weeks of heavy precipitation produce ideal conditions for these pathogens to thrive and proliferate, leading to higher concentrations in the environment. Previous studies have found these enteric pathogens in environmental samples throughout Georgia so the trends from this study are possibly due to an increase in pathogen concentration in the soil and surface water following wet antecedent precipitation conditions. Flooding events caused by heavy precipitation can wash these enteric pathogens into untreated recreational water sources (i.e. lakes, rivers, streams, etc.) and increase likelihood of people to encounter these pathogens at an infectious dose level. One explanation for these findings is the combination of increased pathogen concentration in the environment due to the wet antecedent conditions combined with the increased likelihood of participation in outdoor/water related activities, particularly in untreated recreational water, during the drier week. People may be more likely to spend time outdoors and in untreated recreational water sources when precipitation is low, especially after multiple weeks of high precipitation.

A major limitation to this study is that the date of onset is not uniformly collected when reported to the Georgia Department of Public Health. The date of onset is entered by the reporting entity (the lab or physician that received the positive diagnosis) and the date could vary between symptom onset or sample collection date. The average incubation period of these pathogens also ranges from 6 hours-7 days, although for some pathogens the incubation period can last up to 14 days. Symptom onset could occur in a range of times after exposure to the pathogen and the actual exposure date is nearly impossible to determine even with accurate symptom onset dates. The precipitation of the entire 7 days prior to disease onset was considered as the primary exposure to attempt to offset this variation as disease exposure cannot be determined.

Another limitation is that case incidence increased in recent years due to more sensitive and comprehensive diagnostic technology being developed. Case incidence likely increased since 2015 due to the transition from culture-based diagnostic testing to culture-independent diagnostic testing; however, case incidence was increasing prior to this advancement in diagnostic testing indicating there was a rise in cases due to some external factor. Year and season of disease onset were used to account for case variation, however, due to a smaller sample of cases from earlier years, we have a less comprehensive association for the entire 20-year period.

Finally, not all those who experience enteric disease symptoms seek treatment and therefore less severe cases are less likely to be tested and captured with current notifiable disease reporting standards. The current standards require positive lab-confirmed diagnoses to be reported to the Georgia Department of Public Health, however those with less severe symptoms may not seek treatment or produce a stool sample for lab testing and therefore would not be reported. This is likely why a large portion of cases are seen in pediatric patients as parents are more likely to seek treatment for their children than young adults are to seek treatment for themselves for enteric disease symptoms.

Conclusions

This study quantifies the association between enteric disease incidence and both long and short-term precipitation conditions over an extensive time period. Current literature focuses on salmonellosis incidence while lacking evidence for other enteric pathogens which are of interest due to current climate trends. Precipitation and extreme-weather events are expected to increase in coming decades due to climate change and understanding the impact of this increase on enteric disease incidence can help to inform future studies and educational programs.

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Table 1: Case Demographics

Demographics for all eligible enteric disease cases across the 20-year study period, 2000-2019.

Table 1. Case Demographics

Characteristic	**Overall**, N = 71,691[1]	**Disease** **CAMPYLOBACTERIOSIS**, N = 17,181[1]	**CRYPTOSPORIDIOSIS**, N = 5,430[1]	**SALMONELLOSIS**, N = 45,544[1]	**STEC**, N = 3,536[1]
Gender					
FEMALE	34,627 (48%)	7,637 (44%)	2,347 (43%)	22,738 (50%)	1,905 (54%)
MALE	36,643 (51%)	9,436 (55%)	3,071 (57%)	22,512 (49%)	1,624 (46%)
Unknown	421 (0.6%)	108 (0.6%)	12 (0.2%)	294 (0.6%)	7 (0.2%)
Race					
AMERICAN INDIAN/ALASKA NATIVE	116 (0.2%)	35 (0.2%)	3 (<0.1%)	70 (0.2%)	8 (0.2%)
ASIAN	1,147 (1.6%)	330 (1.9%)	68 (1.3%)	651 (1.4%)	98 (2.8%)
BLACK	13,997 (20%)	2,232 (13%)	1,780 (33%)	9,360 (21%)	625 (18%)
HAWAIIAN/PACIFIC ISLANDER	52 (<0.1%)	16 (<0.1%)	2 (<0.1%)	33 (<0.1%)	1 (<0.1%)
MULTIRACIAL	701 (1.0%)	122 (0.7%)	39 (0.7%)	471 (1.0%)	69 (2.0%)
WHITE	43,935 (61%)	11,279 (66%)	2,772 (51%)	27,539 (60%)	2,345 (66%)
Unknown	11,743 (16%)	3,167 (18%)	766 (14%)	7,420 (16%)	390 (11%)
Ethnicity					
HISPANIC	4,510 (6.3%)	1,409 (8.2%)	228 (4.2%)	2,482 (5.4%)	391 (11%)
NON-HISPANIC	45,783 (64%)	10,538 (61%)	3,734 (69%)	28,784 (63%)	2,727 (77%)
Unknown	21,398 (30%)	5,234 (30%)	1,468 (27%)	14,278 (31%)	418 (12%)
Age					
Mean (SD)	28.0 (26.2)	35.3 (24.4)	34.6 (21.8)	24.7 (26.8)	25.3 (25.2)
Unknown	212.0 (0.3%)	31.0 (0.2%)	16.0 (0.3%)	160.0 (0.4%)	5.0 (0.1%)

[1] n (%)

Data provided by the Georgia Department of Public Health FoodNET Site

Table 2: Precipitation Characteristics

Classification of antecedent and week-of precipitation for each county day across the 20-year study period, 2000-2019.

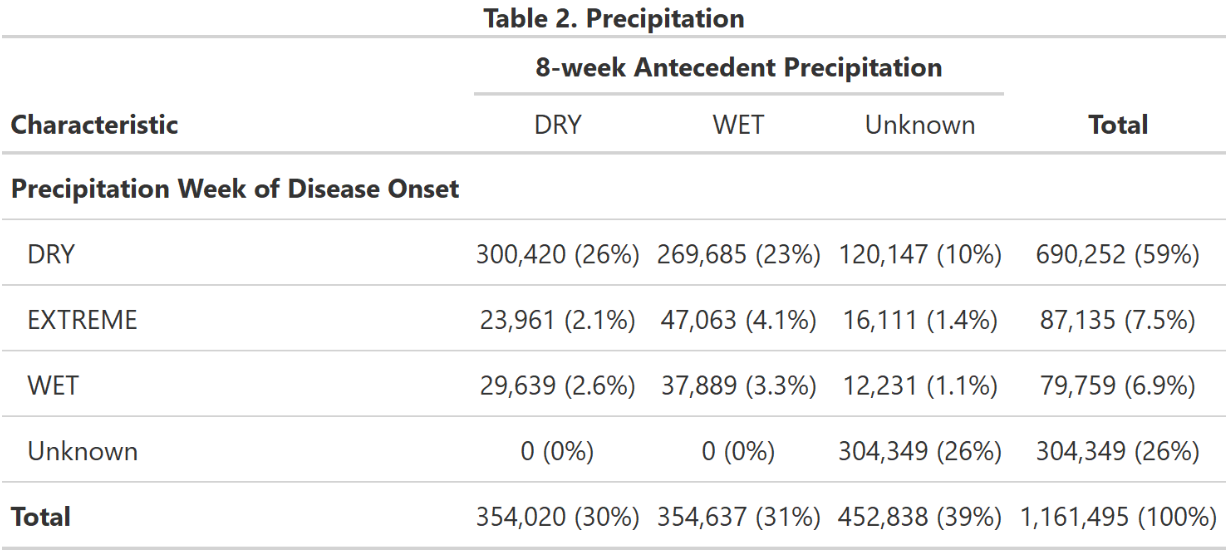
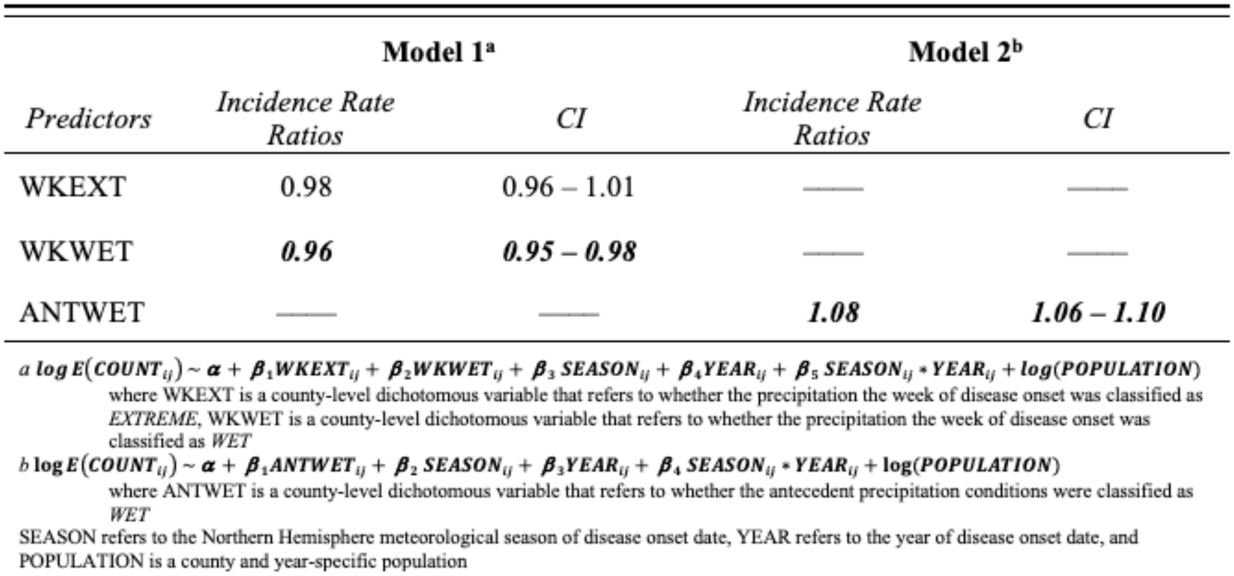


Table 2. Precipitation

	8-week Antecedent Precipitation			
Characteristic	DRY	WET	Unknown	**Total**
Precipitation Week of Disease Onset				
DRY	300,420 (26%)	269,685 (23%)	120,147 (10%)	690,252 (59%)
EXTREME	23,961 (2.1%)	47,063 (4.1%)	16,111 (1.4%)	87,135 (7.5%)
WET	29,639 (2.6%)	37,889 (3.3%)	12,231 (1.1%)	79,759 (6.9%)
Unknown	0 (0%)	0 (0%)	304,349 (26%)	304,349 (26%)
Total	354,020 (30%)	354,637 (31%)	452,838 (39%)	1,161,495 (100%)

Table 3: Overall association between enteric disease incidence and only short-term (week of disease onset) or long-term (antecedent weeks) precipitation conditions.



	Model 1[a]		Model 2[b]	
Predictors	*Incidence Rate Ratios*	*CI*	*Incidence Rate Ratios*	*CI*
WKEXT	0.98	0.96 – 1.01	——	——
WKWET	***0.96***	***0.95 – 0.98***	——	——
ANTWET	——	——	***1.08***	***1.06 – 1.10***

[a] $\log E(COUNT_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, SEASON_{ij} + \beta_4 YEAR_{ij} + \beta_5\, SEASON_{ij} * YEAR_{ij} + \log(POPULATION)$

where WKEXT is a county-level dichotomous variable that refers to whether the precipitation the week of disease onset was classified as *EXTREME*, WKWET is a county-level dichotomous variable that refers to whether the precipitation the week of disease onset was classified as *WET*

[b] $\log E(COUNT_{ij}) \sim \alpha + \beta_1 ANTWET_{ij} + \beta_2\, SEASON_{ij} + \beta_3 YEAR_{ij} + \beta_4\, SEASON_{ij} * YEAR_{ij} + \log(POPULATION)$

where ANTWET is a county-level dichotomous variable that refers to whether the antecedent precipitation conditions were classified as *WET*

SEASON refers to the Northern Hemisphere meteorological season of disease onset date, YEAR refers to the year of disease onset date, and POPULATION is a county and year-specific population

Table 4: Overall and disease-specific association between enteric disease incidence and the interaction of short-term (the week of disease onset) and long-term (antecedent weeks) precipitation conditions.

	Model 3		**Model 4**		**Model 5**	
Conditions (Wk, Ant)	*Incidence Rate Ratios*	*CI*	*Incidence Rate Ratios*	*CI*	*Incidence Rate Ratios*	*CI*
Extreme, Wet	***1.04***	***1.01 – 1.07***	1.03	0.99 – 1.08	***1.17***	***1.09 – 1.26***
Extreme, Dry	0.95	0.88 – 1.02	1.02	0.96 – 1.07	0.99	0.90 – 1.09
Wet, Wet	***1.04***	***1.02 – 1.07***	***1.06***	***1.02 – 1.09***	***1.11***	***1.06 – 1.17***
Wet, Dry	***0.96***	***0.94 – 0.99***	***0.96***	***0.93 – 0.99***	1.02	0.97 – 1.08
Dry, Wet	***1.11***	***1.08 – 1.13***	***1.13***	***1.10 – 1.16***	***1.10***	***1.05 – 1.16***
Dry, Dry	——	——	——	——	——	——

	Model 6		**Model 7**	
Conditions (Wk, Ant)	*Incidence Rate Ratios*	*CI*	*Incidence Rate Ratios*	*CI*
Extreme, Wet	0.94	0.80 – 1.09	1.00	0.88 – 1.14
Extreme, Dry	1.09	0.90 – 1.32	0.99	0.85 – 1.17
Wet, Wet	0.91	0.82 – 1.01	1.06	0.98 – 1.16
Wet, Dry	***0.85***	***0.76 – 0.95***	1.04	0.96 – 1.14
Dry, Wet	0.96	0.87 – 1.07	***1.10***	***1.02 – 1.20***
Dry, Dry	——	——	——	——

a $\log E(COUNT_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, ANTWET_{ij} + \beta_4\, SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6\, SEASON_{ij} * YEAR_{ij} + \beta_7\, WKEXT_{ij} * ANTWET_{ij} + \beta_8\, WKWET_{ij} * ANTWET_{ij} + \log(POPULATION)$

where COUNT refers to county-level enteric disease case counts

b $\log E(SALM_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, ANTWET_{ij} + \beta_4\, SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6\, SEASON_{ij} * YEAR_{ij} + \beta_7\, WKEXT_{ij} * ANTWET_{ij} + \beta_8\, WKWET_{ij} * ANTWET_{ij} + \log(POPULATION)$

where SALM refers to county-level salmonellosis case counts

c $\log E(CAMPY_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, ANTWET_{ij} + \beta_4\, SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6\, SEASON_{ij} * YEAR_{ij} + \beta_7\, WKEXT_{ij} * ANTWET_{ij} + \beta_8\, WKWET_{ij} * ANTWET_{ij} + \log(POPULATION)$

where CAMPY refers to county-level campylobacteriosis case counts

d $\log E(STEC_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, ANTWET_{ij} + \beta_4\, SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6\, SEASON_{ij} * YEAR_{ij} + \beta_7\, WKEXT_{ij} * ANTWET_{ij} + \beta_8\, WKWET_{ij} * ANTWET_{ij} + \log(POPULATION)$

where STEC refers to county-level STEC case counts

e $\log E(CRYPTO_{ij}) \sim \alpha + \beta_1 WKEXT_{ij} + \beta_2 WKWET_{ij} + \beta_3\, ANTWET_{ij} + \beta_4\, SEASON_{ij} + \beta_5 YEAR_{ij} + \beta_6\, SEASON_{ij} * YEAR_{ij} + \beta_7\, WKEXT_{ij} * ANTWET_{ij} + \beta_8\, WKWET_{ij} * ANTWET_{ij} + \log(POPULATION)$

where CRYPTO refers to county-level cryptosporidiosis case counts

WKEXT is a county-level dichotomous variable that refers to whether the precipitation the week of disease onset was classified as *EXTREME*, WKWET is a county-level dichotomous variable that refers to whether the precipitation the week of disease onset was classified as *WET*, and ANTWET is a county-level dichotomous variable that refers to whether the antecedent precipitation conditions were classified as *WET* SEASON refers to the Northern Hemisphere meteorological season of disease onset date, YEAR refers to the year of disease onset date, and POPULATION is a county and year-specific population

Figure 1: Average annual county-level enteric disease incidence rate

Average annual county-level enteric disease case incidence per 100,000 residents over the 20-year study period, 2000-2019.

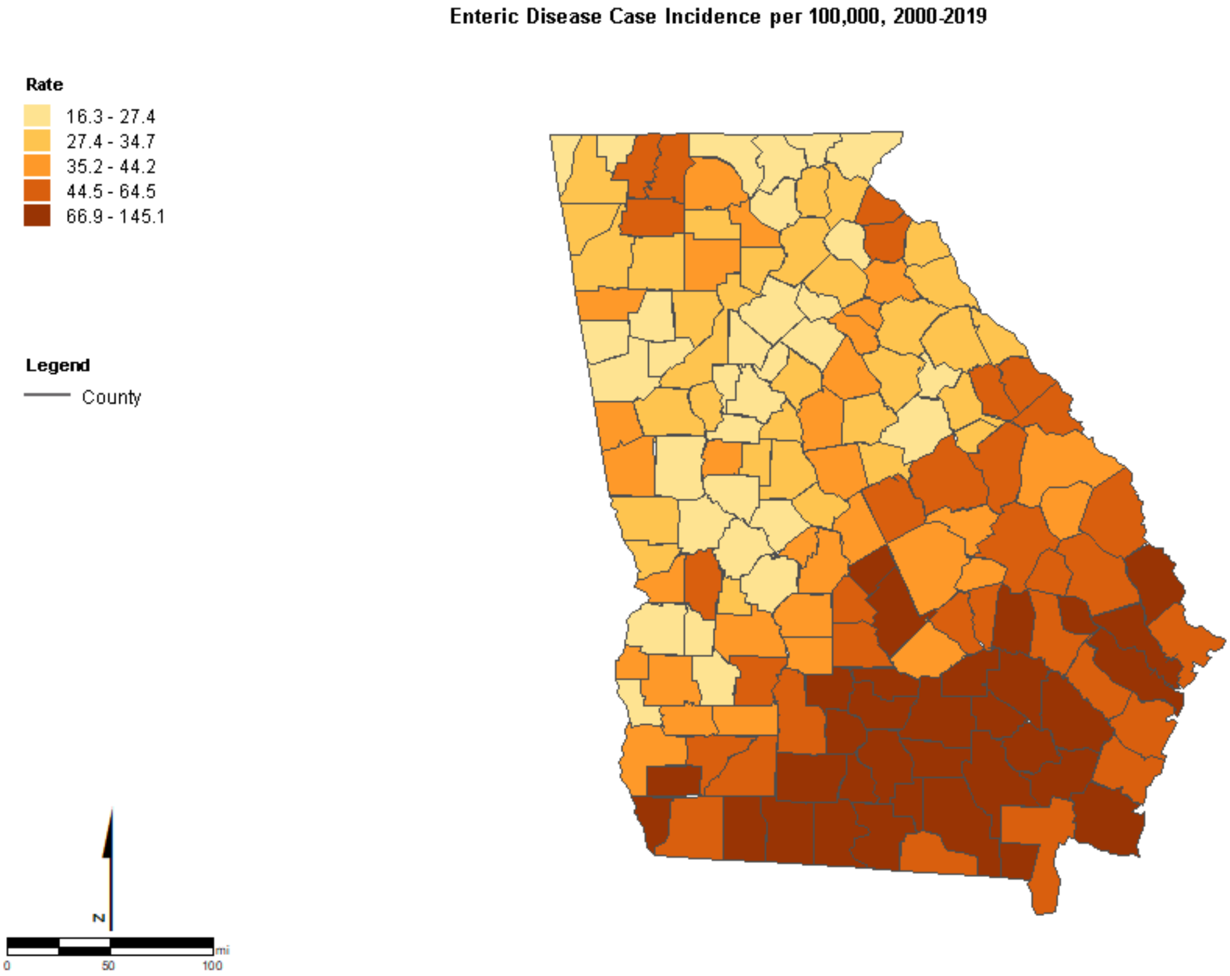
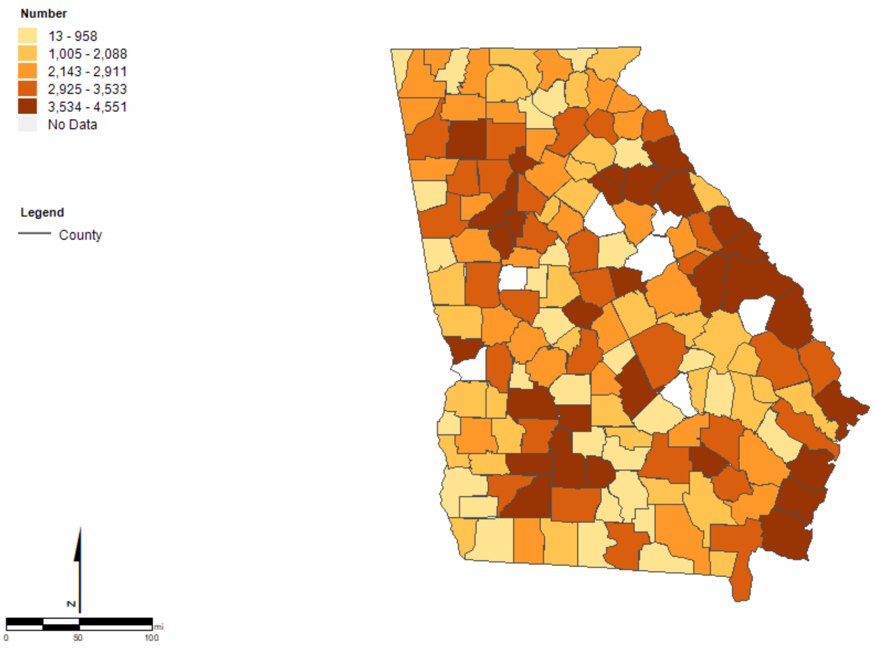
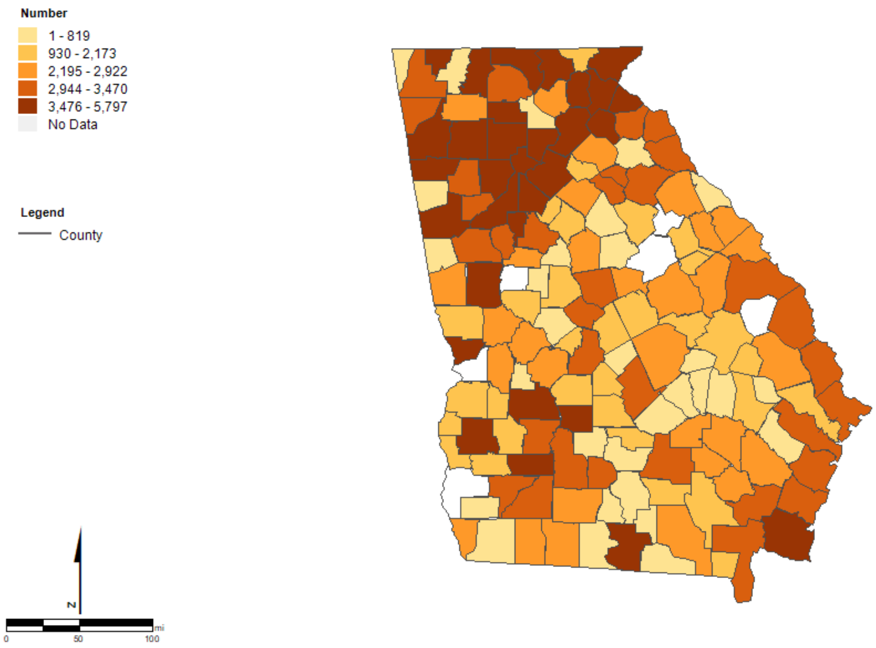


Figure 2: Total number of county-level antecedent wet v dry days

County-level total number of days for which antecedent conditions were classified as *WET* and *DRY* over the 20-year study period, 2000-2019.



Total Number of Antecedent "Dry" Days by County, 2000-2019



Total Number of Antecedent "Wet" Days by County, 2000-2019

Figure 3: Total number of county-level week of precipitation extreme v wet v dry days

County-level total number of days for which precipitation the week of disease onset was classified as *EXTREME, WET,* and *DRY* over the 20-year study period, 2000-2019.

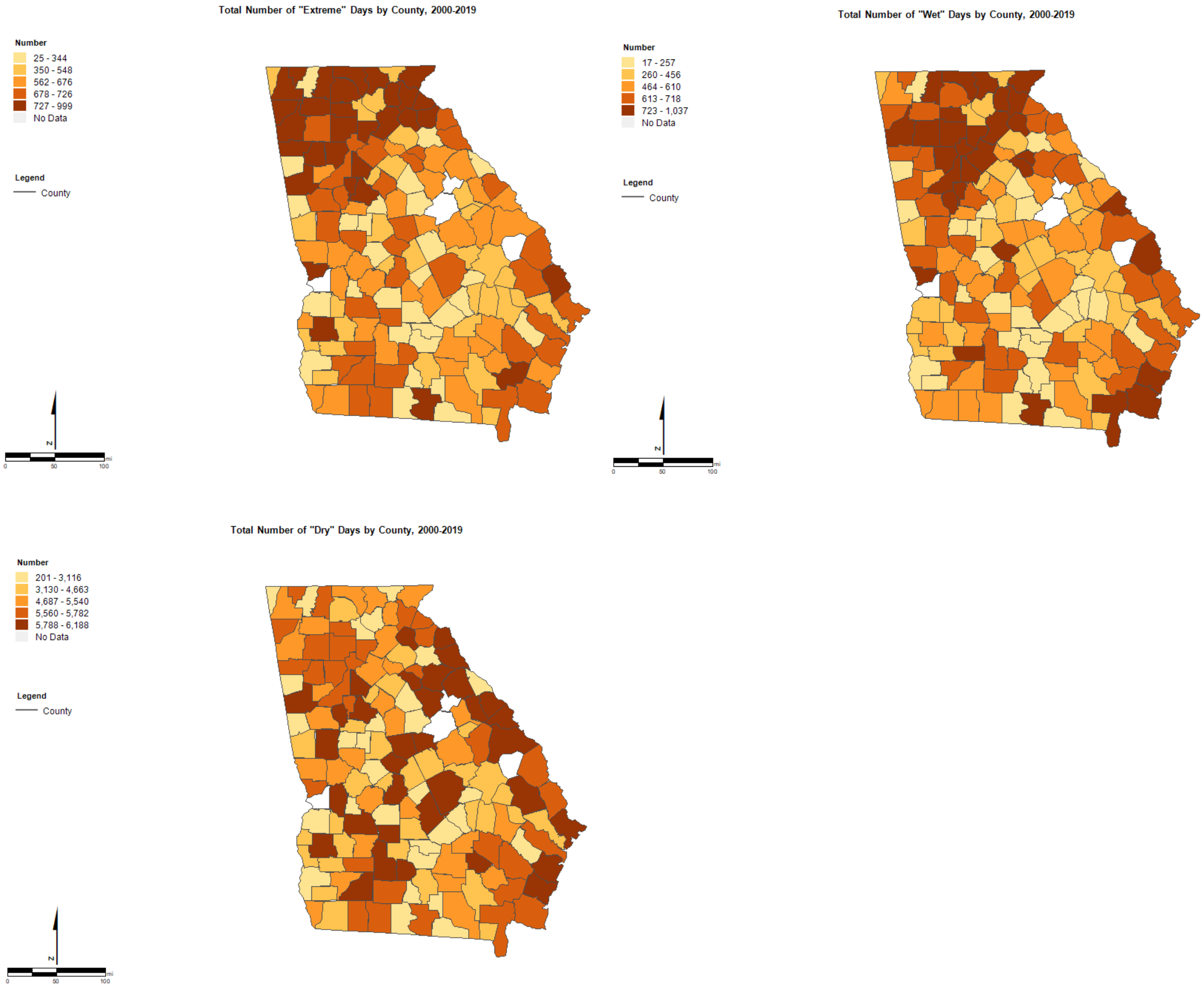


Figure 4: Annual case count v average annual precipitation

Total number of reported enteric disease cases by year and average annual precipitation over the 20-year study period.