

Fall 12-2018

EFFECTS OF EXTREME PRECIPITATION ON GASTROINTESTINAL RELATED HOSPITAL ADMISSIONS IN TEXAS

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EFFECTS OF EXTREME PRECIPITATION ON GASTROINTESITNAL RELATED
HOSPITAL ADMISSIONS IN TEXAS

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2018

DEDICATION

To Komal Bhandari

EFFECTS OF EXTREME PRECIPITATION ON GASTROINTESTINAL RELATED
HOSPITAL ADMISSIONS IN TEXAS

by

SHARMILA GIRI
BS, TRIBHUVAN UNIVERSITY, 2013

Presented to the Faculty of The University of Texas

School of Public Health

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH
Houston, Texas

December, 2018

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my academic and thesis advisor, Dr. Ruosha Li of the Department of Biostatistics and Data Science at the University of Texas Health Science Center (UTHealth) School of Public Health for her continuous guidance and support from the process of finding a research topic to the process of writing thesis. She made herself available for any questions I had at any time during the entire time of my study at UTHealth, for which I am immensely grateful.

I would also like to thank my thesis supervisor and minor advisor, Dr. Kai Zhang at UTHealth School of Public Health for his immense knowledge, valuable time and continuous guidance. I am equally grateful to my committee member Dr Chunyan Cai for her valuable feedbacks on my thesis.

Finally, I would like to express my profound gratitude to my family and friends, for providing me with unfailing support and continuous encouragement throughout my time in school. Special thanks to my husband Komal, without whom nothing would have been possible. Thank you all for supporting me in this arduous yet enriching journey!

EFFECTS OF EXTREME PRECIPITATION ON GASTROINTESTINAL RELATED HOSPITAL ADMISSIONS IN TEXAS

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Extreme precipitation has been implicated in more than 51% of the waterborne disease outbreaks in the United States between 1948-1994. With increased incidence of extreme precipitation projected to be more likely due to ongoing climate change, the burden of waterborne disease is expected to rise even in the United States where drinking water is considered to be one of the safest in the world. In this study we aim to quantify the risk of extreme precipitation on gastrointestinal (GI) related hospital admissions by using meteorological and emergency hospital data from twelve major metropolitan statistical areas (MSA) of Texas from year 2004 to 2013. We used distributed lag non-linear model with quasi Poisson regression to estimate the relative risk of GI-related hospital admission occurring at the certain value of precipitation (90th, 95th and 99th percentile) following 15-day period to the probability of the event occurring at the reference value of no precipitation (0 mm). The results showed that the cumulative risk of GI-related hospital admission following days with extreme precipitation was consistently elevated in overall as well as age stratified population in most of the MSAs. The relative risks were significantly higher in children under 6 years and elderly above 65 years compared to adults between 6 to 65 years. The largest effect was observed in Corpus Christi with an estimated relative risk of 2.19 [95% CI: 1.35,3.54] among children under 6 years and 1.65 [95% CI: 1.33, 2.05] among elderly population above 65 years. The results from casue specific analysis showed diarrheal specific causes were responsible for most of the risks observed compared to pathogen or other/ill-defined causes. The findings underscore the need for development of policies and infrastructures to address the effects of extreme precipitation on global/local disease burden given the projected increase in such inclement weather events in the future.

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1. Background

The on-going global climate change accelerated by anthropogenic greenhouse gas emissions-particularly from burning fossil fuels and deforestation over last few decades and resulting climatic variability have potential to bring myriad of human health consequences through its complex and intricate effects on food and water security, air quality, and disease etiology.^{5,9,20,21} The increasing evidence from studies carried out in recent years have shown that extreme weather events such as heavy rainfall and subsequent flooding, increased droughts, and intense tropical storms are becoming more common and are likely to worsen in the future.^{9-11,14-18} One of the major effects of changing climate on weather that can have immediate impact on human health is increasingly variable rainfall intensity and patterns.²¹ Flooding and increased runoff following heavy rainfall can compromise the supply of fresh drinking water through its potential contamination with microbial, organic, and chemical pollutants. Contamination of drinking water is well-documented risk factors for transmission of several diarrheal diseases, which is reported to kill over 500,000 children aged under 5 years, every year.^{19, 21} Some of the pathogens that contribute to major outbreak of waterborne illness especially in underdeveloped nations every year includes *Vibrio Cholerae*, *Escherichia coli* (*E. coli*), *Shigella*, *salmonella*, *rotavirus*, and *cryptosporidium*.⁵ Report from World Health Organization (WHO) states that waterborne diseases are one of the major contributors to global disease burden and mortality.²¹ Though not as pressing public health burden as it is in the developing nations, diarrheal disease still remains a persistent concern that requires effective attention in the developed nations such as the United States.²² In a study carried out from 1948-1994, about fifty-one percent of waterborne disease outbreaks in the United States were preceded by extreme precipitation.¹⁰ Improving the understanding of dynamics between human health and extreme weather-related events such as extreme precipitation is an important step towards finding both mitigation and adaptation strategy in reducing the associated public health burden from diarrheal disease.⁵ At time when climate change is predicted to increase both the frequency and intensity of extreme weather events in many regions across globe, proper understanding of these events is vital to developing strategic public health policies and intervention programs that aims to increase resilience of people towards these kinds of events in the future.^{5,9,21}

2. Literature Review

2.1 Climate Change and Precipitation

According to Intergovernmental Panel on Climate Change (IPCC,2001) report, the global mean surface temperature rose by about 0.7 to 1.4 °F during the last century.²⁶ During the same time span, contiguous United States temperature has increased by approximately 1°F.²⁶⁻³⁰ This increasing global temperature have been found to be associated with increased ocean temperatures and eventual increase in the amount of evaporation from warmer oceans.²⁴ When the moisture-laden air moves across the land or converges into a tropical storm system, it can produce intense precipitation in the form of heavy rainfall and snow storms.^{24,25}

Numerous recent studies across continental United States as well as report from U.S. Third National Climate Assessment (May 2014) have found that there have been significant increase in number and intensity of extreme precipitation events over the wide range of duration in recent years.^{23,30} According to the report published by United States Environmental Protection Agency (USEPA,2016), the total annual precipitation has increased at an average rate of 0.008 inches per decade over land areas in the United States and worldwide since 1901.²⁴ The same report states that the increase in precipitation accounted by intense single-day rainfall events which have increased potential for causing severe flooding and excess runoff.

2.2 Extreme Precipitation and Human Health

The human health is sensitive to shifts in weather patterns and if the climate change continues as projected, it will be affected through events such as greater risk of injury, disease, and death from heat waves and wildfires, as well as increased risk of food, water and vector borne diseases.^{5,31} Since climate change is predicted to bring more extreme weather events such as intense precipitation, increased flood and droughts around the globe, it is important to assess the impact such events will have on human health to mitigate the future risk on life and property.^{5,9-11,14} It is also equally important to identify the high risk groups such as children, elderly population, immunocompromised individuals, pregnant women, indigenous and marginalized community, as they are especially vulnerable to effects of extreme weather events such as heavy rainfall, storms and heat waves.^{5,31}

Extreme precipitation or heavy rainfall events are known to be complicit in transmitting gastrointestinal infections around the world.^{3-5,9-11,13,20-22} Extreme precipitation can mobilize the

pathogens in the environment and increase the run-off from fields and streets, transporting fecal matters, sewage, and parasites to water sources such as rivers, wells, and coastal water, resulting in water sources contamination.³¹⁻³³ People can become exposed to such contaminated water either through direct ingestion of contaminated food or water or indirectly while swimming, or other recreational activities during which contact through eyes, ears and open wounds serves as major pathways of human exposure.^{31,34,35} According to report by CDC on waterborne illness in the United States, exposure to contaminated water have been found to cause deaths, emergency department visits, and hospitalization associated with thirteen major water transmitted diseases. Some of which include campylobacteriosis, cryptosporidiosis, *Escherichia coli* (*E. coli*), giardiasis, salmonellosis, shigellosis, and vibriosis or cholera.^{35,37-39}

2.3 Incidence of Gastrointestinal Illness following Extreme Precipitation

Drinking water in the United States are considered to be the safest in the world but there is also an increasing concern as floods and other severe weather events following extreme precipitation can lead to outbreaks of waterborne diseases by disruption of drinking water supply system that are aging and long overdue for replacement.³⁵⁻³⁶ Several studies have been carried out to explore the association between extreme precipitation and GI-related hospital admissions. Rainfall and run-off following precipitation above 90th percentile was implicated in 51% of the waterborne disease outbreaks in the United States between 1948-1994.¹⁰ Another study aimed to look at the burden of Gastrointestinal disease in the United States found that the risk of GI related hospitalizations was increased among consumers whose drinking water source was impacted by combined sewer overflows after extreme precipitation.⁴⁰ Study carried out in Massachusetts found that flooding was associated with an increased risk of emergency room visits for gastrointestinal illness in a 0 to 4 day period after heavy rainfall.³⁶ The result from study in Vietnam found that the level of infectious intestinal disease increased from 7.3% to 13.5% for lags from 0 to 21 days following high rainfall event.²⁰ Similar outcomes were observed in Sweden, where prolonged wet weather lead to increased acute gastrointestinal illness, bolstering the hypothesis that water contamination following heavy rainfall is associated with increased risk of waterborne illness.⁴¹ In Taiwan, extreme torrential precipitation (>350mm/day) was found to result in a higher relative risk for bacillary dysentery and enterovirus infections when compared to ordinary rain (<130 mm/day).⁴² The same study found that differential lag effects following precipitation were statistically associated with increased

risk of contracting individual infectious diseases. The largest drinking water outbreak ever documented in the United States occurred in Milwaukee in 1993, caused by *Cryptosporidium parvum*, resulted in an estimated 403,300 cases of intestinal illness and 54 deaths.⁴⁵ Preceding period of heavy rainfall and runoff which overwhelmed the water filtration and disinfection system were blamed for this outbreak.^{46,47} Another largest outbreak associated with *E. coli* O1557:H7 occurred at fairground in the state of New York in 1999 was also linked to contamination of well water after heavy rains.^{48,34}

2.4 Public Health Significance

Mortality and morbidity from infectious diseases have declined sharply in the United States during 20th century due to improvement in areas of sanitation and hygiene, strategic vaccination, development of antibiotics and other antimicrobial medicines, and advancement in diagnostic tools.⁴³ Although deaths from infectious diseases have declined overall in the past decades, the number of deaths attributed to diarrheal disease have increased substantially from 1980 to 2014 in nearly all the counties in the US, making it a second-leading cause of all infectious disease mortality behind lower respiratory infections.⁴⁴

Evidence from several past studies have shown that despite having the safest drinking water supply in the world, community water systems in the United States can still be overburdened by the extreme rainfall and lead to increased risk of waterborne illness.^{35,36,49} CDC's report on magnitude and burden of waterborne disease in the United States found that there were 6,939 annual total deaths and 477,000 annual emergency department visits in year 2017 from pathogens that can be transmitted by water.³⁷⁻³⁹ The financial burden from waterborne illness hospitalizations was estimated \$3.8 billion.^{37,39} The true cost is estimated to be much higher than reported because it did not include all the waterborne pathogens as well as the less severe illness that did not resulted in death or hospitalization.³⁹ Despite gastrointestinal disease being one of the most preventable disease, its spread still remains a major public health concern due to increasing extreme precipitation pattern.

The changing weather pattern have been noticed in Texas climate too with rainstorms becoming more intense and floods becoming more severe. A recent MIT study reported that the annual risk of extreme rainfall for state of Texas will rise from 1 to 18 percent by the end of this

century.^{50,51} The study also highlighted that as the climate change progresses, the state will face more devastating rainfall and consequences it brings with it.^{50,51} Despite Texas being one of the states to be hard hit by the extreme precipitation events every year, very few studies have been carried out to assess the impacts such events have on incidence of gastrointestinal diseases. This will be the first study carried out using time-series analysis of both weather and hospitalization data from 2004 to 2013 in the state of Texas to assess the public health burden of gastrointestinal disease following extreme precipitation. We also aim to focus our analysis on children and elderly as they are more vulnerable to such events compared to healthy adult population. The results from the study will be an important additional tool in planning for adaptation and interventions programs aimed at reducing the burden from GI-related disease.

2.5 Specific Aim of the Study

Environmental stressors such as extreme precipitation often produce effects that are delayed in time. The goal of this study is to assess the relationship between extreme precipitation and Gastrointestinal (GI) related hospital admission in twelve major Texas Metropolitan Statistical Areas (MSAs) accounting for the lagged effect of precipitation using both meteorological and emergency hospital admission data from 2004 through 2013. We hypothesize that the number of hospitalizations for GI-related illness will be spiked for several days following an event of extreme precipitation. The rationale behind this hypothesis is that the increased runoff and flooding following heavy rainfall can wash off the pollutants and pathogens from streets and agricultural land into water bodies resulting in increased risk of water source contamination. Exposure to such contaminated water via drinking water supply or recreational water use can eventually lead to increased number of infections from GI-related illness if appropriate precautions are not put in place. We also hypothesize that the infection rates are higher in children and elderly population due to their weaker immune system as compared to healthier adults. In our study we focus to investigate the potential health impact and lag effects of multiple daily weather factors on GI related illness, and also assess if the impacts vary by age group and specific causes of gastrointestinal infections, namely pathogen, diarrheal and other or ill-defined.

3. Methods

3.1 Study Area

Texas is the second largest state of the United States after Alaska and the second most populous state after California.¹ As of February 2013, 25 Texas Metropolitan Statistical Areas (MSAs) are delineated by the U.S. Office of Management and Budget (OMB) based on the current 2010 Census Bureau data.² Twelve Texas MSAs whose population size were consistently over 200,000 throughout the study period (2004 to 2013) were selected for the study. The selection was also based on the availability of data on meteorological parameters.

3.2 Data Sources

3.2.1 Emergency Hospital Admissions Data

Emergency Hospital Admissions (HA) data was obtained from the Texas Department of State Health Services (DSHS). Cause of admission was defined as Gastrointestinal related (GI) if the primary, secondary, or tertiary ICD-9 code was classified as

- (i) a pathogen specific intestinal infectious disease (ICD 001-007; 120-129),
- (ii) other and ill-defined intestinal infectious disease (008-009), or
- (iii) diarrheal disease-related symptoms (276, 558.9, 787)³⁻⁵

Emergency Hospital Admission (HA) data were extracted from all available hospital admission data based on type of admissions (Emergency; and Urgent). They were then collapsed into daily counts of GI- related hospital admissions for each of the twelve MSAs. Patient level information available from Emergency Hospital Admissions data were also included.

3.2.2 Meteorological Data

Hourly weather data collected at weather stations across Texas were obtained from the National Climate Data Center (NCDC) through the Integrated Surface Database (ISD).⁶ For each MSA, one weather station that is the best representative of its population exposure such as closest airport weather stations was selected.² Meteorological parameters such as daily total precipitation, mean, minimum, and maximum temperature, dew point, and humidity were included in the dataset for further analysis. Daily total precipitation was used as primary exposure of interest. We used MSA specific 90th percentile precipitation for entire study period from 2004-2013 as extreme precipitation based on definition used by Bush et. al.⁵

3.3 Statistical Analysis

We studied the relationship between GI-related hospital admissions and precipitation across major twelve MSAs of Texas using time series regression. The statistical analysis comprised of both descriptive analysis and statistical modeling. All the analyses were performed using R software version 3.5.1 using package *dlm* version 2.3.5.⁵⁴

3.3.1. Lagged Effect

Previous studies carried out to assess the association between extreme precipitation and GI-related hospital admission have found that the rate of hospitalizations increases for several days after the extreme precipitation, suggesting the delayed effect of exposure outcome relationship.^{5,9-11,13} This is explained due to the varying range of transportation time of waterborne pathogens to source of water and their incubation period.⁵ In order to account for this variability, the association between GI-related hospital admissions and precipitation across twelve MSAs in Texas was studied across 15-day lag since the incubation period for most of the pathogens of interest in our study fell between one day for *Shigella*, *Salmonella* and *Rotavirus* to up to two weeks for *E. coli* and *Cryptosporidium*.⁵

3.3.2 Confounding Effect

Meteorological factor such as mean apparent temperature was considered a potential confounder in our study as higher apparent temperature has been found to be detrimental to health of vulnerable population such as elderly and children and conducive to replication, persistence, and transmission of several waterborne pathogens.^{5,9} Apparent temperature (AT) calculated using the formula: $AT = -2.653 + (0.994 * T_a) + (0.0153 * T_d^2)$, where T_a is equal to air temperature ($^{\circ}C$) and T_d is equal to dew point temperature ($^{\circ}C$), is also known as perceived temperature for the indicated hour.⁶ An indicator variable representing day of the week (DOW) was also considered as a potential confounder since the studies have found that hospitalization rate differs significantly between weekends and weekdays due to the so called “weekend effect”.^{5,52} The long-time trends, seasonality and several other unmeasured covariates were controlled by including natural cubic splines of time as day of year (DOY) ranging from 1 to 365.⁵⁴

3.3.3 Descriptive Analysis

Descriptive summary of the variables under study such as daily total precipitation, mean apparent temperature, and GI-related hospital admissions across each MSAs were summarized with appropriate statistics. Time series plots of hospital admissions and precipitation were created to check for consistency and to observe seasonal trends (Figure 1). Distribution of daily total precipitation throughout entire study period were also assessed using appropriate summary measures.

3.3.4 Statistical Model

For quantifying the risk of GI-related hospital admission associated with precipitation across major Texas MSAs, we applied distributed lag non-linear model (dlm) developed by Gasparrini et al in 2010 with quasi-Poisson regression model. We assumed that GI-related hospital admissions followed an over-dispersed Poisson (quasi-Poisson) distribution. Over dispersion in such distribution is accounted by fitting quasi-maximum likelihood Poisson models that allows the scale parameter to be different from the mean and produce estimator that is robust to distributional misspecification.^{55, 56} To account for the incubation period of several waterborne pathogens and subsequent GI-related infection on human, we analyzed the exposure- delayed outcome association with 0-15-day lag period. We designed a distributed lag non-linear model which is an appropriate method for modeling non-linear exposure-outcome relationships over time by using cross-basis functions.^{54, 57}

The cross-basis function is a bi-dimensional space of functions describing simultaneously the shape of relationship along predictor and its distributed lag effects.⁵⁴ The detailed theoretical derivation of cross basis function from two basis functions: one along the dimension of variable and another along the dimension of lag which can be found in Gasparrini's paper. In our study, we used quadratic B-spline as the basis for precipitation and natural cubic spline for lag. The choice of the basis function was motivated from substantive and methodological studies on time series analysis of short-term environmental exposures such as heat wave, air pollution and extreme precipitation.⁵⁴ The degree of freedom for both variable and lag basis were based on the results from exploratory data analysis, results from previous studies, and also based on the information criteria quasi AIC/quasi BIC.⁵⁸ In the analysis, the knots for each basis were placed

at equally spaced values of their logarithmic scale to allow more flexibility in the first part of the distributed curve where higher variability is expected.⁵⁴

The results from the model were presented as the relative risk which is defined as the probability of GI-related hospital admission occurring at the certain value of precipitation (90th, 95th and 99th percentile) following 15-day period to the probability of the event occurring at the reference value of no precipitation (0 mm).⁵⁸ The choice of reference point is based on interpretational issue as it has no effect on the fit of the model.^{58,54} The results were first estimated for 90th percentile precipitation and for those MSAs where 90th percentile present no effect, 95th and 99th percentile precipitation were used to compute the relative risk comparing with no precipitation.

The MSA specific associations were estimated through the quasi-Poisson regression model as follows:

$$\text{Log}[E(HA_t)] = \beta_0 + \beta_1(DOW_t) + \text{cb}(\text{PRCP}_{t,1}) + S1(AT_t) + S2(DOY_t)$$

Where,

$E(HA_t)$ = Expectation of daily GI-related hospital admissions at day t

$\text{PRCP}_{t,1}$ = Daily total precipitation (mm) on lag day 1, 1 ranges from 0 to 15 days

AT_t = Daily average apparent temperature at day t(°C)

DOW_t = An indicator variable for the day of the week

DOY_t = Day of year, ranges from 1 to 365

$S1$ = Natural cubic splines of apparent temperature with 3 degrees of freedom

$S2$ = Natural cubic splines of time with 7 degrees of freedom per year

β_0, β_1 = Intercept, vector of regression coefficients

cb = Cross-basis function of precipitation

The association between precipitation and GI-related hospital admissions among children age less than 6 years and elderly above 65 years as well as cause-specific associations were also

computed using similar modeling approach. Model diagnostics was done by checking the residuals for its assumption of normality and constant variance.

4. Results

A total of 1,478,680 GI-related hospital admissions were reported during the entire study period with highest from Dallas (33%) and lowest from Waco (1%). Elderly population of more than 65 years of age accounted for 42% (619,332) and children under 6 years of age accounted for 8% (114,480) of the total GI-related hospital admissions during the study period of 2004 to 2013. The average number of daily admissions for all age group ranged from 6 in Waco to 134 in Dallas (Table 1). Daily precipitation showed a highly skewed distribution. Out of total 43,836 days in the entire study period, 1,121 days had missing values for precipitation and 8,800 days had precipitation greater than 0 mm. The average daily precipitation in Texas MSAs ranged from 0.55 mm in El Paso to 2.37 mm in Houston or 4.37 mm in El Paso to 9.07 mm in Killen (Table 2) if only days with precipitation were analyzed. The overall 90th and 95th percentile precipitation for entire study area were 3.04 mm and 9.70 mm respectively. The mean apparent temperature was consistent throughout the MSAs ranging between 15.23 °C in Lubbock to 26.56 °C in Brownsville (Table 3). For cause specific admissions, diarrheal disease related admissions accounted for 94% of the total GI related admissions in the entire study period with pathogen and other/ill-defined admissions accounting for less than 1% and 5% respectively.

Table 1: Descriptive statistics on daily GI-related hospital admissions across twelve Texas MSAs

	All Ages		Less Than 6 years		6-65 Years		More Than 65 years	
MSA	N	Mean \pm SD	N	Mean \pm SD	N	Mean \pm SD	N	Mean \pm SD
Austin	106,107	29 \pm 8	3,379	1 \pm 1	58,207	16 \pm 5	44,521	12 \pm 4
Beaumont	33,509	9 \pm 3	3,314	1 \pm 1	14,148	4 \pm 2	16,047	4 \pm 2
Brownsville	33,450	9 \pm 4	5,533	1 \pm 2	13,083	4 \pm 2	14,834	4 \pm 2
Corpus	41,562	11 \pm 4	4,128	1 \pm 1	19,265	5 \pm 2	18,169	5 \pm 2
Dallas	489,674	134 \pm 23	30,401	8 \pm 4	253,960	70 \pm 14	205,313	56 \pm 11
El Paso	79,494	22 \pm 6	10,478	3 \pm 2	33,188	9 \pm 4	35,828	10 \pm 3
Houston	387,748	106 \pm 18	28,438	8 \pm 4	203,449	56 \pm 11	155,861	43 \pm 9
Killeen	27,835	8 \pm 3	3,002	1 \pm 1	13,386	4 \pm 2	11,447	3 \pm 2
Lubbock	31,511	9 \pm 3	2,110	1 \pm 1	15,363	4 \pm 2	14,038	4 \pm 2
McAllen	77,815	21 \pm 7	11,692	3 \pm 2	37,583	10 \pm 5	28,540	8 \pm 3
San Antonio	149,503	41 \pm 8	9,523	3 \pm 2	73,781	20 \pm 6	66,199	18 \pm 5
Waco	20,472	6 \pm 3	2,482	1 \pm 1	9,455	3 \pm 2	8,535	2 \pm 2
Total (%)	1,478,680		114,480 (8%)		744,868 (50%)		619,332 (42%)	

Table 2: Descriptive statistics of precipitation across twelve Texas MSAs

	Overall daily precipitation (mm)					Wet day precipitation (mm)				
MSA	Min	Mean \pm SD	90%	95%	Max	Min	Mean \pm SD	90%	95%	Max
Austin	0	1.86 \pm 9.99	3.64	10.19	302.1	0.06	8.67 \pm 20.19	21.53	30.67	302.13
Beaumont	0	2.60 \pm 8.24	7.83	16.15	119.3	0.08	8.99 \pm 13.31	23.95	34.86	119.25
Brownsville	0	1.42 \pm 6.44	2.41	7.84	109.1	0.06	6.96 \pm 12.84	16.96	31.65	109.06
Corpus	0	1.40 \pm 7.11	2.05	7.64	205	0.06	6.97 \pm 14.57	17.4	27.59	204.96
Dallas	0	1.79 \pm 6.49	4.15	12.51	90.18	0.06	8.88 \pm 12.07	23.66	34.88	90.18
El Paso	0	0.55 \pm 2.76	0.51	2.97	53.8	0.08	4.36 \pm 6.57	11.7	18.65	53.8
Houston	0	2.37 \pm 7.80	6.85	15.85	108.8	0.06	9.00 \pm 13.08	23.73	34.4	108.81
Killeen	0	1.90 \pm 8.25	2.79	11.49	145.4	0.05	9.06 \pm 16.14	26.14	36.46	145.42
Lubbock	0	0.98 \pm 4.46	1.52	5.64	133.3	0.05	5.63 \pm 9.39	15.35	22.63	133.34
McAllen	0	1.09 \pm 5.38	1.27	5.43	100.8	0.08	6.26 \pm 11.60	16.43	24.43	100.84
San Antonio	0	1.54 \pm 6.61	2.95	8.79	173	0.08	7.39 \pm 12.93	19.52	30.26	173.01
Waco	0	1.85 \pm 7.02	3.84	11.88	106.1	0.08	8.96 \pm 13.23	23.27	36.83	106.11

Table 3 : Descriptive statistics of mean apparent temperature (°C)

MSA	Min.	Mean \pm SD	Median	Max
Austin	-5.47	21.27 \pm 10.27	22.60	36.97
Beaumont	-3.59	22.47 \pm 09.86	23.92	37.73
Brownsville	-3.28	26.56 \pm 08.17	28.19	40.63
Corpus	-3.86	25.08 \pm 09.14	26.92	38.04
Dallas	-7.99	19.98 \pm 11.00	20.75	38.82
El Paso	-9.70	17.60 \pm 08.88	18.22	33.15
Houston	-4.29	22.78 \pm 09.91	24.27	38.68
Killeen	-6.63	20.55 \pm 10.19	21.53	38.80
Lubbock	-11.16	15.23 \pm 10.13	15.32	33.64
McAllen	-2.89	26.34 \pm 08.41	28.23	38.71
San Antonio	-5.05	22.19 \pm 09.70	23.50	36.27
Waco	-6.88	20.29 \pm 10.82	21.11	37.77

The distributed lag non linear model (dlm) used in our analysis gave the effect estimates of relationship between extreme precipitation and GI-related hospital admission by accounting for not only non-linear dependencies between them but also the delayed effect extreme precipitation had on GI-related hospital admission. The visual inspection of the three dimensional (Figure 2) and lag-specific (Figure 4) figures for each MSAs suggest that extreme precipitation (90th percentile) was associated with increased risk of overall GI-related hospital admission in most of the MSAs, and the risk varied along the lags with higher risks observed within first 5 days. At least nine out of twelve MSAs showed positive association in at least one of the age categories between exposure and outcome for MSA specific 90th percentile precipitation compared to no precipitation (table 4). The largest and statistically significant increase was observed in Corpus Christi with an estimated relative risk of 2.19 [95% CI: 1.35,3.54] among children under 6 years and 1.65 [95% CI: 1.33, 2.05] among elderly population above 65 years. Seven out of twelve MSAs had the relative risk of 90th percentile precipitation elevated among children under 6 years ranging from 1.01 [95% CI: 0.46, 2.23] in Waco to 2.19 [95% CI: 1.35, 3.54] in Corpus Christi, though not all were statistically significant. Similar results were observed in elderly population

with five MSAs showing positive association where highest cumulative risk was observed in Corpus Christi 1.65 [95% CI: 1.33, 2.05] followed by Killen, 1.56 [95% CI: 1.11, 2.17]. El paso, which had the lowest average daily precipitation among all the MSAs in the study showed the protective effect for children and adults but increased though non-significant risk for elderly population with estimated relative risk of 1.11 [95% CI: 0.87,1.41].

For MSAs Austin, McAllen, and San Antonio, where 90th percentile precipitation showed no increased risk, we assessed the risk at 95th and 99th percentile precipitation respectively because we assumed the outcome would be increased with increased precipitaon level. The results from overall population showed that the relative risk was elevated though not significant in McAllen 1.10 [95% CI: 0.89, 1.37] for 95th percentile precipitation compared to no precipitation. Similarly elevated relative risks were observed in Austin 1.27 [95% CI: 1.01, 1.61], and San Antonio 1.10 [95% CI: 0.95, 1.28] for 99th percentile precipitaion where both 90th and 95th percentile precipitaion showed rather protective effect. Results exhibited similar trend when stratified by age. All the results by age group for 90th percentile preceipitation are summarized in Table 4.

For cause specific analysis, the diarrheal disease specific results were consistent with overall results. The realtive risk of pathogen specific hospital admissions were found positive in five of the MSAs ranging from 1.17 [95% CI: 0.32, 4.22] in Brownsville to 2.62 [95% CI: 0.6, 11.41] in Corpus Christi. None of the pathogen specific positive associations were statistically significant except for Houston 2.24 [95% CI: 1.33, 3.77]. The results from other or ill-defined causes were also similar to that of pathogen specific causes (Table 5).

Table 4: The overall Cumulative risk (RR)^a of GI-related hospital admission associated with extreme precipitation (90th percentile) by age group for all twelve MSAs estimated by distributed lag non linear model with 15-days lag.

Overall GI-related HA risk of MSA specific extreme precipitation (90th percentile) Vs No precipitation				
MSA	All Ages	Less than 6 Years	6-65 Years	above 65 Years
Austin	0.72 (0.66, 0.80)	0.22 (0.13, 0.36)	0.71 (0.63, 0.80)	0.80 (0.71, 0.90)
Beaumont	0.96 (0.82, 1.13)	1.31 (0.79, 2.16)	1.01 (0.79, 1.25)	0.88 (0.71, 1.10)
Brownsville	1.48 (1.24, 1.77) *	1.47 (0.97, 2.20)	1.50 (1.19, 1.89) *	1.48 (1.17, 1.87) *
Corpus	1.40 (1.21, 1.63) *	2.19 (1.35, 3.54) *	1.08 (0.87, 1.34)	1.65 (1.33, 2.05) *
Dallas	0.92 (0.85, 1.01)	1.05 (0.80, 1.35)	0.89 (0.80, 1.00)	0.94 (0.85, 1.04)
El Paso	1.04 (0.88, 1.22)	0.48 (0.28, 0.83)	0.64 (0.49, 0.83)	1.11 (0.87, 1.41)
Houston	1.06 (1.01, 1.13) *	1.39 (1.13, 1.71) *	1.06 (0.98, 1.15)	1.01 (0.92, 1.10)
Killen	1.36 (1.08, 1.71) *	0.96 (0.47, 1.98)	1.28 (0.93, 1.76)	1.56 (1.11, 2.17) *
Lubbock	0.96 (0.81, 1.13)	1.63 (0.89, 2.99)	1.05 (0.83, 1.33)	0.79 (0.62, 1.00)
McAllen	0.63 (0.54, 0.73)	0.65 (0.45, 0.93)	0.50 (0.40, 0.61)	0.85 (0.69, 1.04)
San Antonio	0.88 (0.82, 0.94)	0.91 (0.70, 1.17)	0.81 (0.73, 0.90)	0.96 (0.87, 1.05)
Waco	0.82 (0.62, 1.17)	1.01 (0.46, 2.23)	0.67 (0.45, 1.01)	0.94 (0.63, 1.39)

Abbreviations: GI-Gastrointestinal, HA-Hospital Admissions, ^a Model estimates are adjusted for mean apparent temperature, day of week and long-term time trend, *significant estimates.

Table 5: The overall Cumulative risk (RR)^a of GI-related hospital admission associated with extreme precipitation (90th percentile) by cause of admissions for all twelve MSAs estimated by distributed lag non linear model with 15-days lag.

Overall GI-related HA risk of MSA specific extreme precipitation (90%) Vs No precipitation				
MSA	Overall	Diarrheal Specific	Pathogen Specific	Other /Ill Defined
Austin	0.72 (0.66, 0.80)	0.73 (0.66, 0.80)	0.95 (0.43, 2.13)	0.67 (0.5, 0.89)
Beaumont	0.96 (0.82, 1.13)	0.96 (0.82, 1.12)	0.85 (0.12, 5.86)	1.01 (0.5, 2.00)
Brownsville	1.48 (1.24, 1.77) *	1.51 (1.26, 1.82) *	1.17 (0.32, 4.22)	1.36 (0.73, 2.51)
Corpus	1.40 (1.21, 1.63) *	1.47 (1.26, 1.72) *	2.62 (0.6, 11.41)	0.85 (0.50, 1.44)
Dallas	0.92 (0.85, 1.01)	0.92 (0.84, 1.00)	0.82 (0.44, 1.53)	0.87 (0.69, 1.10)
El Paso	1.04 (0.88, 1.22)	0.80 (0.67, 0.96)	0.45 (0.08, 2.44)	0.98 (0.53, 1.81)
Houston	1.06 (1.01, 1.13) *	1.06 (1.01, 1.13) *	2.24 (1.33, 3.77) *	1.25 (1.04, 1.51) *
Killen	1.36 (1.08, 1.71) *	1.34 (1.06, 1.70) *	0.3 (0.01, 5.15)	1.69 (0.85, 3.37)
Lubbock	0.96 (0.81, 1.13)	0.98 (0.82, 1.16)	0.75 (0.008, 7.07)	0.64 (0.36, 1.11)
McAllen	0.63 (0.54, 0.73)	0.64 (0.55, 0.75)	1.82 (0.52, 6.32)	0.29 (0.16, 0.53)
San Antonio	0.88 (0.82, 0.94)	0.91 (0.85, 0.97)	0.39 (0.19, 0.81)	0.56 (0.44, 0.69)
Waco	0.82 (0.62, 1.17)	0.85 (0.65, 1.13)	2.19 (0.17, 27.34)	0.31 (0.12, 0.77)

Abbreviations: GI-Gastrointestinal, HA-Hospital Admissions, ^a Model estimates are adjusted for mean apparent temperature, day of week and long-term time trend, *significant estimates.

5. Discussion

The results from distributed lag nonlinear model in our study showed that the cumulative risk of GI-related hospital admission following days with extreme precipitation was consistently elevated in overall as well as age stratified population in most of the MSAs. The relative risks were significantly higher in children under 6 years and elderly above 65 years compared to adults between 6 to 65 years. This is consistent with the hypothesis that the risk would be elevated in vulnerable populations with weaker immune system. When observed across cause specific associations, the results from diarrheal specific causes were consistent with overall causes. This is not surprising given that almost 94% of the GI-related hospital admissions were due to diarrheal specific causes. Either of pathogen specific or Other/ill-defined associations showed positive associations in at least nine of the MSAs but only Houston had significant relative risk with 2.24 [95% CI: 1.33, 3.77] for pathogen specific hospital admissions and 1.24 [95% CI: 1.04, 1.51] for other/ill-defined causes of admissions. The smaller sample size for pathogen specific admissions and Other/Ill-defined admissions could be attributed to insignificant association with higher confidence intervals found in most of the MSAs.

The results from our study is in line with the study carried out by Schwartz et al in Philadelphia where they found that there were increased emergency department visits for GI-related disease among children and elderly, 4 days following the increased turbidity in drinking water.⁴ Similar result was found by Jagai et al in Massachusetts where region with combined sewer overflow outfalls saw the 13% increase in GI-related illness over an 8-day period for all age group following precipitation above 99th percentile compared to no precipitation.³⁶ Another study carried out in Ecuador by Levy et al found that heavy precipitation was associated with increased diarrhea incidence with incidence rate ratio of 1.39 [95%CI: 1.03, 1.87] following relatively dry periods.⁵⁹

The lag specific association as shown in Figure 4 suggests that the increase in hospital admissions starts to elevate after second day of extreme precipitation which would suggest shorter incubation period if the contamination have been caused by bacterial pathogens. This shortly elevated risk could also be explained by possible drinking water infrastructures infiltration by sewage from sewage/sanitary pipe flowing in proximity as extreme precipitation can put tremendous stresses on the storm-water system.⁵⁷ Flooding and streets runoff that are

almost always preceded by events of extreme precipitation can cause series of health problems due to reasons including but not limited to, damage to water supply systems, insufficient drinking water supplies, damage to transportation systems, and most important of all, drinking water contaminations with microorganisms, industrial wastes, and other adverse chemical pollutants.⁶¹ However, we had no access to such data on drinking water breach during our study period. Excess GI-related hospital admissions varied with MSAs, age groups, cause of admissions, and level of precipitation. Coastal MSAs, especially Corpus Christi, Houston, Brownsville, and Beaumont showed the significant relative risk. This could be explained by the instances of increased stormwater runoff and sewage treatment plant bypasses into the bays or bays tributaries following events of extreme precipitation and people becoming potentially exposed to such sewage contaminated water through recreational activities such as swimming and fishing. Most of the MSAs in our study showed the increasing trend in GI-related hospital admissions with increased level of precipitation.

Effects of short-term environmental exposures such as extreme precipitation and GI-related hospital admission have been mostly studied using time series regression with distributed lag model (DLM) which allows the model to give detailed representation of time-course of exposure-outcome relationship.^{9,54} While DLMs are highly effective in providing overall effect in the presence of delayed linear contributions, they fall short when there is non-linear and complex relationship between exposure and outcome. Since the meteorological factors such as temperature, humidity, and precipitation have been found to exhibit non-linear relationship, the method we used (dlm) relaxes the linearity assumption and provides a modeling framework that flexibly describe the associations showing potential non-linear and delayed effects.⁵⁴ In this study, we used the cross-basis of precipitation to estimate the effect along the dimension of precipitation as well as delayed effect as similar approach was used in a study carried out to assess the impact of climatic factors including precipitation in dengue incidence in Sri Lanka by Talagala.⁵⁸

Despite the novel method used in assessing exposure-delayed outcome relationship in our study, there were certain limitations that restricts the generalizability of the study results. The primary limitation of this study is that people often tend to self-medicate and seek less physician consultation for most of the GI-related illness which results in highly underreported incidences.

Often times it is difficult to determine the etiology of illness in such case since GI-related illness shows symptoms that are shared by many other illnesses including food borne diseases.^{5,60} Underreported data that does not capture the true proportion of infected populations has potential to produce biased results possibly attenuating the true effect size. In spite of the possibility of underreporting, the data in our study used ICD codes to identify the cause of GI-related illness, so outcome misclassification have been avoided with proper diagnosis. Another major limitation of this study is ecological fallacy i.e. inferences about individual behavior drawn from data about population. This limitation is inherent to any kind of population level studies since the analysis does not uses individual level characteristics such as socio-economic status, exposure to contaminated water, personal hygiene practices, and combined sewer overflows which could all modify the relationship between extreme precipitation and GI-related hospital admissions. But given the cost and resources associated with carrying out patient level studies of such extent, this study attempts to provide reliable estimates of public health burden by efficient the use of available data and appropriate methods.

6. Conclusion

This study presented the evidence that extreme precipitation indeed increased the GI-related illness burden in country like United States where drinking water supply is considered to be the safest in the world. The risk of GI-related illness is elevated among children and elderly and mostly coastal MSAs. Diarrheal specific causes were responsible for most of the risks observed compared to pathogen or other/ill-defined causes. However, the results from the study should be interpreted with caution due to the inherent nature of ecological study that involves the use of aggregated data and possible exposure misclassification due to data being collected from monitors at central locations that may not be representative of individual level exposures. This warrants the need for future studies with individual approach on several intrinsic (age, gender, clinical and pathological factors) and extrinsic factors (environmental, socio-economic and behavioral such as quality of drinking water, sanitation habits, race and ethnicity, housing, etc) to provide risk estimates that can be inferred at individual level. Despite the limitations of study design, the findings underscore the need for development of policies and infrastructures to address the effects of extreme precipitation on global/local disease burden given the projected increase in such inclement weather events in the future.

7. References

1. US Census Bureau. "Idaho Is Nation's Fastest-Growing State, Census Bureau Reports." U.S. Trade with Haiti. December 20, 2017. Accessed July 24, 2018. <https://www.census.gov/newsroom/press-releases/2017/estimates-idaho.html>.
2. Chen, Tsun-Hsuan, Xiao Li, Jing Zhao, and Kai Zhang. "Impacts of Cold Weather on All-cause and Cause-specific Mortality in Texas, 1990–2011." *Environmental Pollution* 225 (2017): 244-51.
3. Morris, R. D., E. N. Naumova, R. Levin, and R. L. Munasinghe. 1996. Temporal variation in drinking water turbidity and diagnosed gastroenteritis in milwaukee. *American Journal of Public Health* 86 (2): 237-9.
4. Schwartz, Joel, Ronnie Levin, and Rebecca Goldstein. 2000. Drinking water turbidity and gastrointestinal illness in the elderly of philadelphia. *Journal of Epidemiology and Community Health* (1979-) 54 (1): 45-51.
5. Bush, Kathleen F., Cheryl L. Fossani, Shi Li, Bhramar Mukherjee, Carina J. Gronlund, and Marie S. O'Neill. 2014. Extreme precipitation and beach closures in the great lakes region: Evaluating risk among the elderly. *International Journal of Environmental Research and Public Health* 11 (2): 2014-32.
6. "Integrated Surface Database (ISD)." National Climatic Data Center. Accessed July 24, 2018. <http://www.ncdc.noaa.gov/isd>.
7. Smith, Adam, Neal Lott, and Russ Vose. 2011. The integrated surface database: Recent developments and partnerships. *Bulletin of the American Meteorological Society* 92 (6): 704-8.
8. The international classification of diseases, 9th revision, clinical modification: ICD-9-CM1991. United States.
9. Bush, Kathleen F., Marie S. Oneill, Shi Li, Bhramar Mukherjee, Howard Hu, Santu Ghosh, and Kalpana Balakrishnan. "Associations between Extreme Precipitation and Gastrointestinal-Related Hospital Admissions in Chennai, India." *Environmental Health Perspectives*, 2013.

10. Curriero, Frank C., Jonathan A. Patz, Joan B. Rose, and Subhash Lele. "The Association Between Extreme Precipitation and Waterborne Disease Outbreaks in the United States, 1948–1994." *American Journal of Public Health* 91, no. 8 (2001): 1194-199.
11. Rose, Joan B., Scott Daeschner, David R. Easterling, Frank C. Curriero, Subhash Lele, and Jonathan A. Patz. "Climate and Waterborne Disease Outbreaks." *Journal - American Water Works Association* 92, no. 9 (2000): 77-87.
12. Hastie, Trevor, and Robert Tibshirani. "Generalized Additive Models." *Statistical Science* 1, no. 3 (1986): 297-310.
13. Aramini, J., M. McLean, J. Wilson, J. Holt, R. Copes, B. Allen, and W. Sears. 2000. Drinking water quality and healthcare utilization for gastrointestinal illness in greater vancouver. Canada Communicable Disease Report = Relevé Des Maladies Transmissibles Au Canada 26 (24): 211.
14. "Global Climate Change: Effects." NASA. July 16, 2018. Accessed July 25, 2018. <https://climate.nasa.gov/effects/>.
15. Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR, Mearns LO. 2000. Climate extremes: observations, modeling, and impacts. *Science* 289:2068–2074.
16. Ebi KL, Mills DM, Smith JB, Grambsch A. 2006. Climate change and human health impacts in the United States: an update on the results of the U.S. National Assessment. *Environ Health Perspect* 114:1318–1324; doi:10.1289/ehp.8880.
17. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. 2005. Impact of regional climate change on human health. *Nature* 438:310–317.
18. Patz JA, McGeehin MA, Bernard SM, Ebi KL, Epstein PR, Grambsch A, et al. 2001. The potential health impacts of climate variability and change for the United States. Executive summary of the report of the health sector of the U.S. National Assessment. *J Environ Health* 64:20–28.
19. Greenough G, McGeehin M, Bernard SM, Trtanj J, Riad J, et al. (2001) The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. *Environmental Health Perspectives* 109: 191–198.
20. Phung, Dung, Cordia Chu, Shannon Rutherford, Huong Lien Thi Nguyen, Mai Anh Luong, Cuong Manh Do, and Cunrui Huang. "Heavy Rainfall and Risk of Infectious

Intestinal Diseases in the Most Populous City in Vietnam." *Science of The Total Environment* 580 (2017): 805-12.

21. "Climate Change and Health." World Health Organization. Accessed July 25, 2018.
<http://www.who.int/news-room/fact-sheets/detail/climate-change-and-health>.
22. "Food and Waterborne Diarrheal Disease." Centers for Disease Control and Prevention. December 11, 2014. Accessed July 25, 2018.
https://www.cdc.gov/climateandhealth/effects/food_waterborne.htm.
23. Frei, Allan, Kenneth E. Kunkel, and Adao Matonse. "The Seasonal Nature of Extreme Hydrological Events in the Northeastern United States." *Journal of Hydrometeorology* 16, no. 5 (2015): 2065-085.
24. U.S. Environmental Protection Agency. 2016. Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004. www.epa.gov/climate-indicators.
25. Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds.). 2014. Climate change impacts in the United States: The third National Climate Assessment. U.S. Global Change Research Program. <http://nca2014.globalchange.gov>.
26. Mishra, Ashok K., and Vijay P. Singh. "Changes in Extreme Precipitation in Texas." *Journal of Geophysical Research* 115, no. D14 (2010).
27. Karl TR, Knight RW, Easterling DR, Quayle RG. Indices of climate change for the United States. *B Am Meteorol Soc* 77:279-303 (1996).
28. Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Salinger MJ, Razuvaev V, Plummer N, Jamason P, et al. Maximum and minimum temperature trends for the globe. *Science* 277:364-367 (1997).
29. NRC. Reconciling Observations of Global Temperature Change. Washington, DC: National Academy Press, 2000.
30. Patz, Jonathan A., Michael A. McGeehin, Susan M. Bernard, Kristie L. Ebi, Paul R. Epstein, Anne Grambsch, Duane J. Gubler, Paul Reiter, Isabelle Romieu, Joan B. Rose, Jonathan M. Samet, and Juli Trtanj. "The Potential Health Impacts of Climate Variability and Change for the United States: Executive Summary of the Report of the Health Sector of the U.S. National Assessment." *Environmental Health Perspectives* 108, no. 4 (2000): 367.

31. Smith, K.R., A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.
32. Semenza, Jan C., and Bettina Menne. "Climate Change and Infectious Diseases in Europe." *The Lancet Infectious Diseases* 9, no. 6 (2009): 365-75.
33. Cann, K. F., D. Rh. Thomas, R. L. Salmon, A. P. Wyn-Jones, and D. Kay. "Extreme Water-related Weather Events and Waterborne Disease." *Epidemiology and Infection* 141, no. 04 (2012): 671-86.
34. Rose, Joan B., Paul R. Epstein, Erin K. Lipp, Benjamin H. Sherman, Susan M. Bernard, and Jonathan A. Patz. "Climate Variability and Change in the United States: Potential Impacts on Water- and Foodborne Diseases Caused by Microbiologic Agents." *Environmental Health Perspectives* 109, no. S2 (2011): 211-21.
35. "Water." Centers for Disease Control and Prevention. April 22, 2016. Accessed July 26, 2018. <https://www.cdc.gov/parasites/water.html>.
36. Wade, T. J., C. J. Lin, J. S. Jagai, and E. D. Hilborn. "Flooding and Emergency Room Visits for Gastrointestinal Illness in Massachusetts: A Case-crossover Study." *PloS One*. October 17, 2014. Accessed July 26, 2018. <https://www.ncbi.nlm.nih.gov/pubmed/25329916>.
37. "Healthy Water." Centers for Disease Control and Prevention. August 09, 2017. Accessed July 26, 2018. <https://www.cdc.gov/healthywater/burden/current-data.html>.
38. Gargano JW, Adam EA, Collier SA, Fullerton KE, Feinman SJ, Beach MJ. Mortality from selected diseases that can be transmitted by water — United States, 2003–2009. *J Water Health*. 2017;15(3):438-50.

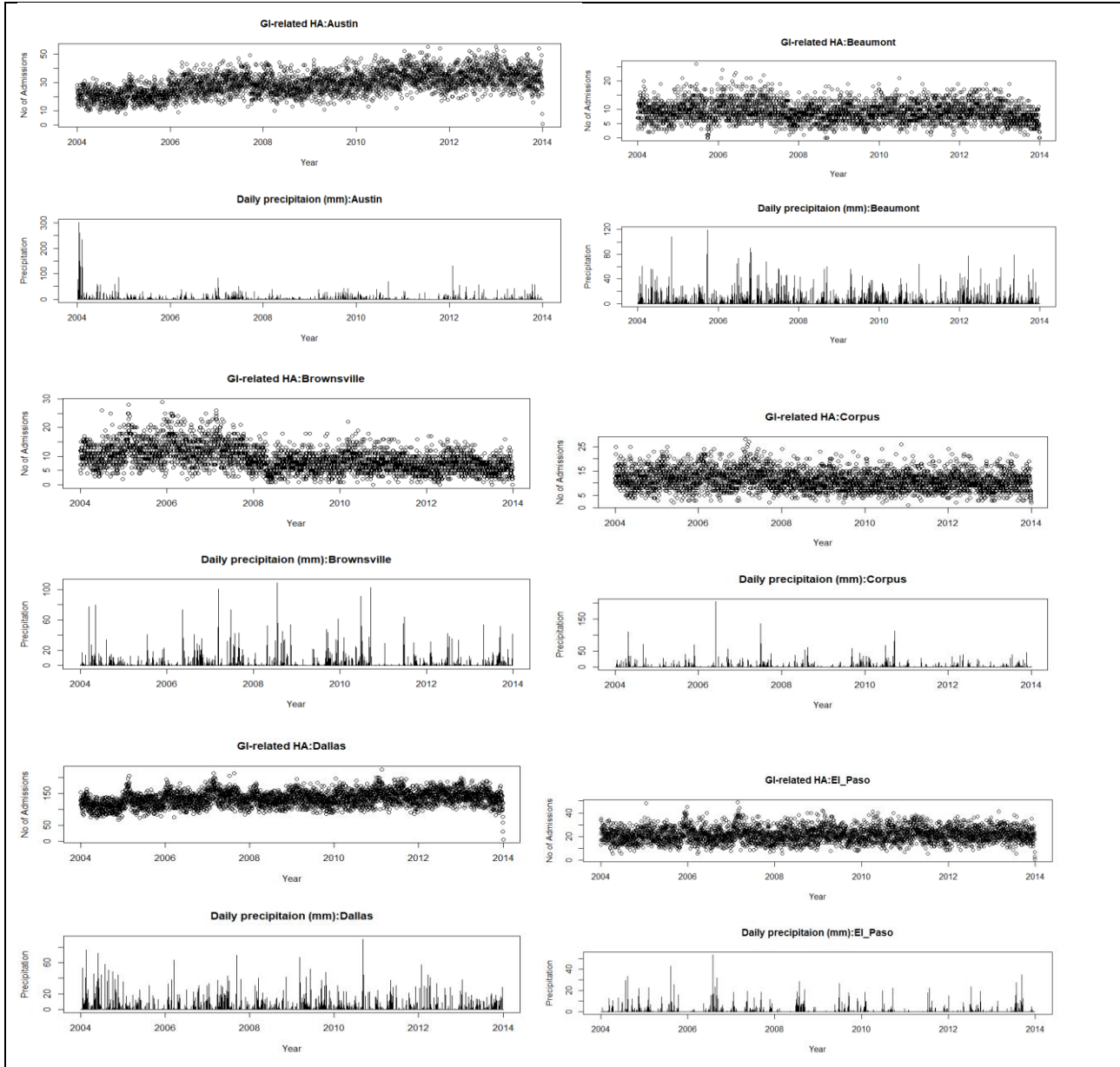
39. Adam EA, Collier SA, Fullerton KE, Gargano JW, Beach MJ. Prevalence and direct costs of emergency department visits and hospitalizations for 13 selected diseases that can be transmitted by water, United States. J Water Health. 2017;wh2017083.
40. "Extreme Precipitation and Emergency Room Visits for Gastrointestinal Illness in Areas with and without Combined Sewer Systems: An Analysis of Massachusetts Data, 2003–2007." National Institute of Environmental Health Sciences. Accessed July 26, 2018. <https://ehp.niehs.nih.gov/1408971/>.
41. Tornevi, Andreas, Lars Barregård, and Bertil Forsberg. "Precipitation and Primary Health Care Visits for Gastrointestinal Illness in Gothenburg, Sweden." *Plos One*10, no. 5 (2015). doi:10.1371/journal.pone.0128487.
42. Chen, Mu-Jean, Pei-Chih Wu, and Huey-Jen Su. "Extreme Precipitation and Climate-related Infectious Diseases in Taiwan (1994–2008)." *Epidemiology*22 (2011).
43. "Achievements in Public Health, 1900-1999: Control of Infectious Diseases." Centers for Disease Control and Prevention. Accessed July 26, 2018. <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm4829a1.htm>.
44. Bcheraoui, Charbel El, Ali H. Mokdad, Laura Dwyer-Lindgren, Amelia Bertozzi-Villa, Rebecca W. Stubbs, Chloe Morozoff, Shreya Shirude, Mohsen Naghavi, and Christopher J. L. Murray. "Trends and Patterns of Differences in Infectious Disease Mortality Among US Counties, 1980-2014." *Jama*319, no. 12 (2018): 1248.
45. Hoxie NJ, Davis JP, Vergeront JM, Nashold RD, Blair KA. Cryptosporidiosis-associated mortality following a massive waterborne outbreak in Milwaukee, Wisconsin. *Am J Public Health* 87:2032–2035 (1997)
46. MacKenzie WR, Hoxie NJ, Proctor ME, Gradus MS, Blair KA, Peterson DE, Kazmierczak JJ, Addiss DG, Fox KR, Rose JB, et al. A massive outbreak in Milwaukee of *Cryptosporidium* infection transmitted through the public water supply. *N Engl J Med* 331:161–167 (1994).
47. Koopman JS, Longini IM Jr. The ecological effects of individual exposures and nonlinear disease dynamics in populations [see Comments]. *Am J Public Health* 84:836–842 (1994).

48. Centers for Disease Control and Prevention. Outbreak of *Escherichia coli* O157:H7 and *Campylobacter* among attendees of the Washington County Fair—New York, 1999. *Mor Mortal Wkly Rep* 48:803 (1999).
49. Patz, Jonathan A., Stephen J. Vavrus, Christopher K. Uejio, and Sandra L. Mclellan. "Climate Change and Waterborne Disease Risk in the Great Lakes Region of the U.S." *American Journal of Preventive Medicine* 35, no. 5 (2008): 451-58.
50. Chu, Jennifer, and MIT News Office. "Texas' Odds of Harvey-scale Rainfall to Increase by End of Century." MIT News. November 13, 2017. Accessed July 26, 2018. <http://news.mit.edu/2017/texas-odds-harvey-scale-rainfall-increase-end-century-1113>.
51. Emanuel, Kerry. "Assessing the Present and Future Probability of Hurricane Harvey's Rainfall." *Proceedings of the National Academy of Sciences* 114, no. 48 (2017): 12681-2684.
52. Flansbaum, Bradley, and Ann M. Sheehy. "In Reference to "The Weekend Effect in Hospitalized Patients: A Meta-Analysis"." *Journal of Hospital Medicine*, 2018
53. Gasparrini, A., B. Armstrong, and M. G. Kenward. "Multivariate Meta-analysis for Non-linear and Other Multi-parameter Associations." *Statistics in Medicine* 31, no. 29 (2012): 3821-839.
54. Gasparrini, A., B. Armstrong, and M. G. Kenward. "Distributed Lag Non-linear Models." *Statistics in Medicine* 29, no. 21 (2010): 2224-234.
55. Cameron, A.colin, and Pravin K. Trivedi. "Regression-based Tests for Overdispersion in the Poisson Model." *Journal of Econometrics* 46, no. 3 (1990): 347-64.
56. Colón-González, Felipe J., Adrian M. Tompkins, Riccardo Biondi, Jean Pierre Bizimana, and Didacus Bambaiha Namanya. "Assessing the Effects of Air Temperature and Rainfall on Malaria Incidence: An Epidemiological Study across Rwanda and Uganda." *Geospatial Health* 11, no. 1s (2016).
57. Tornevi, Andreas, Gösta Axelsson, and Bertil Forsberg. "Association between Precipitation Upstream of a Drinking Water Utility and Nurse Advice Calls Relating to Acute Gastrointestinal Illnesses." *PLoS ONE* 8, no. 7 (2013).
58. Talagala, Thiyanga. "Distributed lag nonlinear modelling approach to identify relationship between climatic factors and dengue incidence in Colombo District, Sri Lanka." *Epidemiology, Biostatistics and Public Health* 12, no. 4 (2015).

59. Carlton, Elizabeth J., Joseph N. S. Eisenberg, Jason Goldstick, William Cevallos, James Trostle, and Karen Levy. "Heavy Rainfall Events and Diarrhea Incidence: The Role of Social and Environmental Factors." *American Journal of Epidemiology* 179, no. 3 (2013): 344-52.
60. Macdougall, L., S. Majowicz, K. Doré, J. Flint, K. Thomas, S. Kovacs, and P. Sockett. "Under-reporting of Infectious Gastrointestinal Illness in British Columbia, Canada: Who Is Counted in Provincial Communicable Disease Statistics?" *Epidemiology and Infection* 136, no. 02 (2007).
61. Sun, Rubao, Daizhi An, Wei Lu, Yun Shi, Lili Wang, Can Zhang, Ping Zhang, Hongjuan Qi, and Qiang Wang. "Impacts of a Flash Flood on Drinking Water Quality: Case Study of Areas Most Affected by the 2012 Beijing Flood." *Heliyon* 2, no. 2 (2016).

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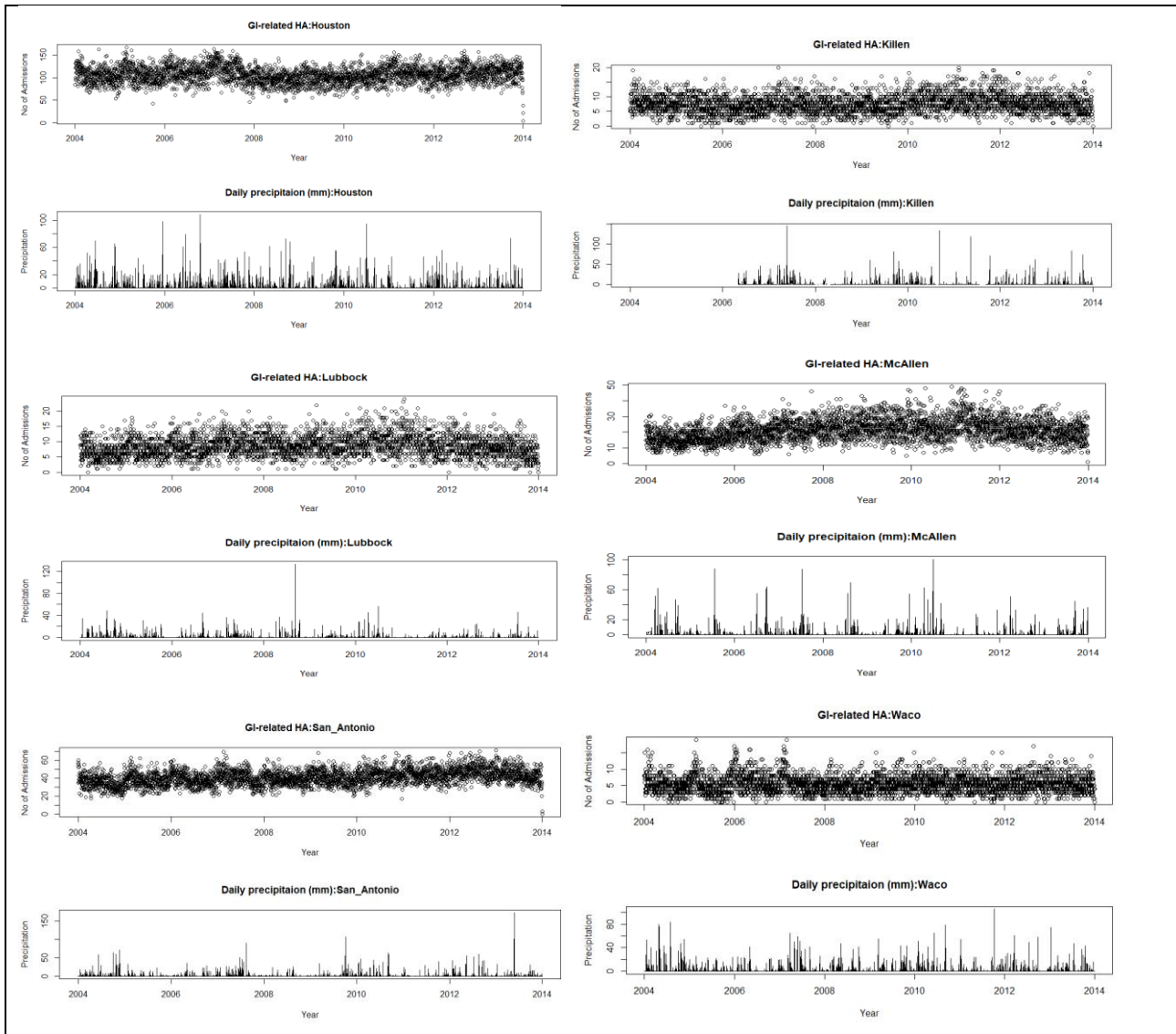


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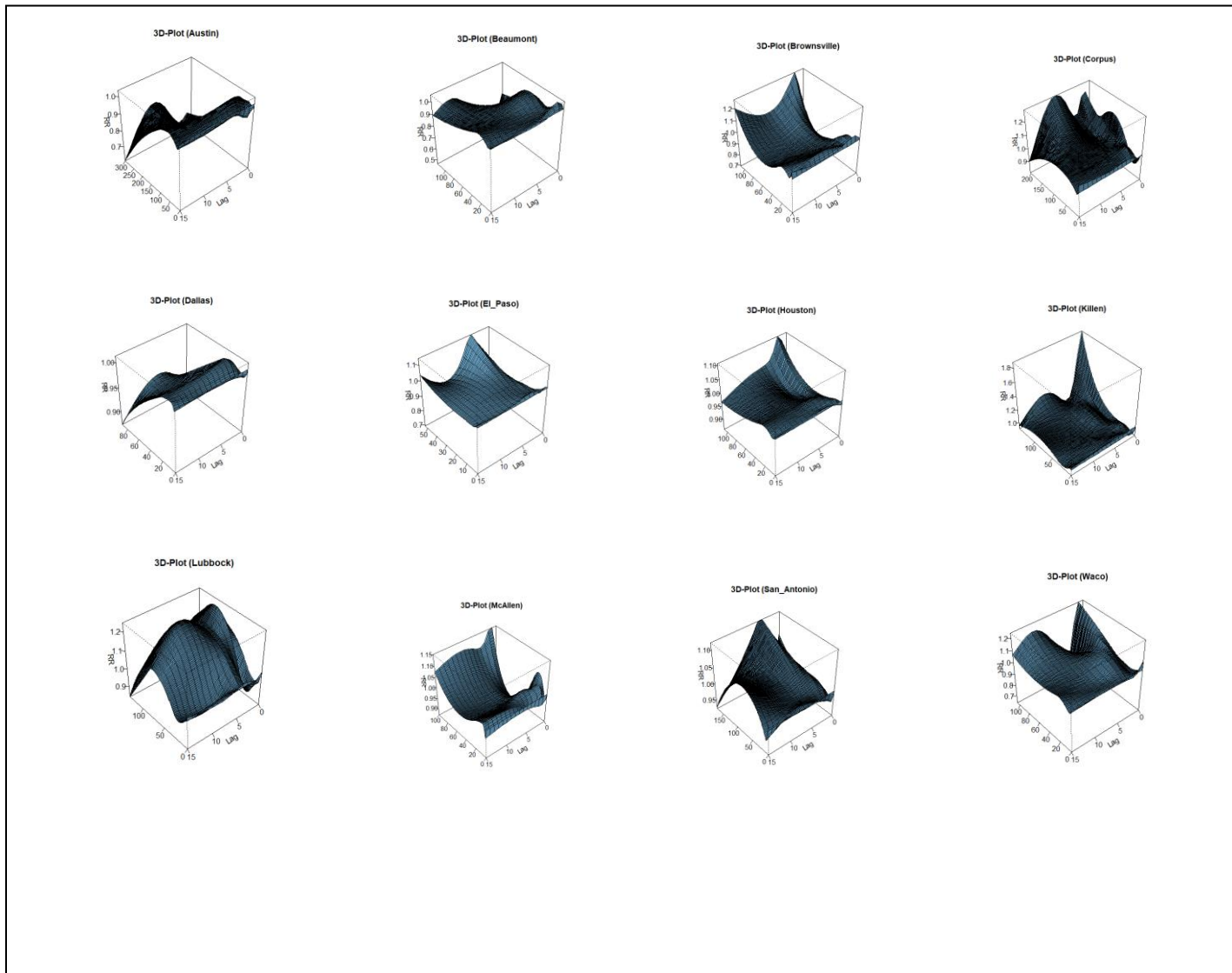


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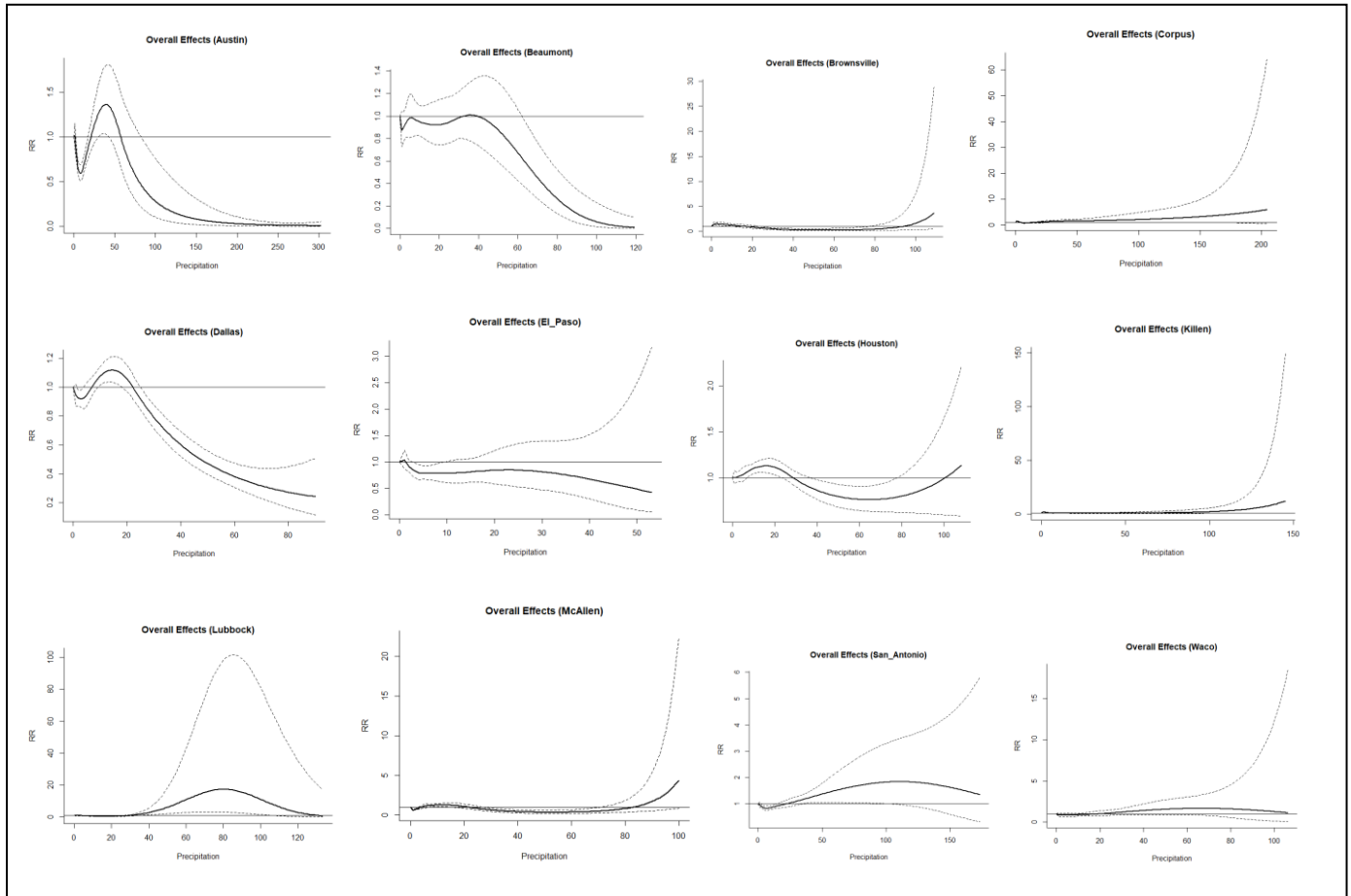


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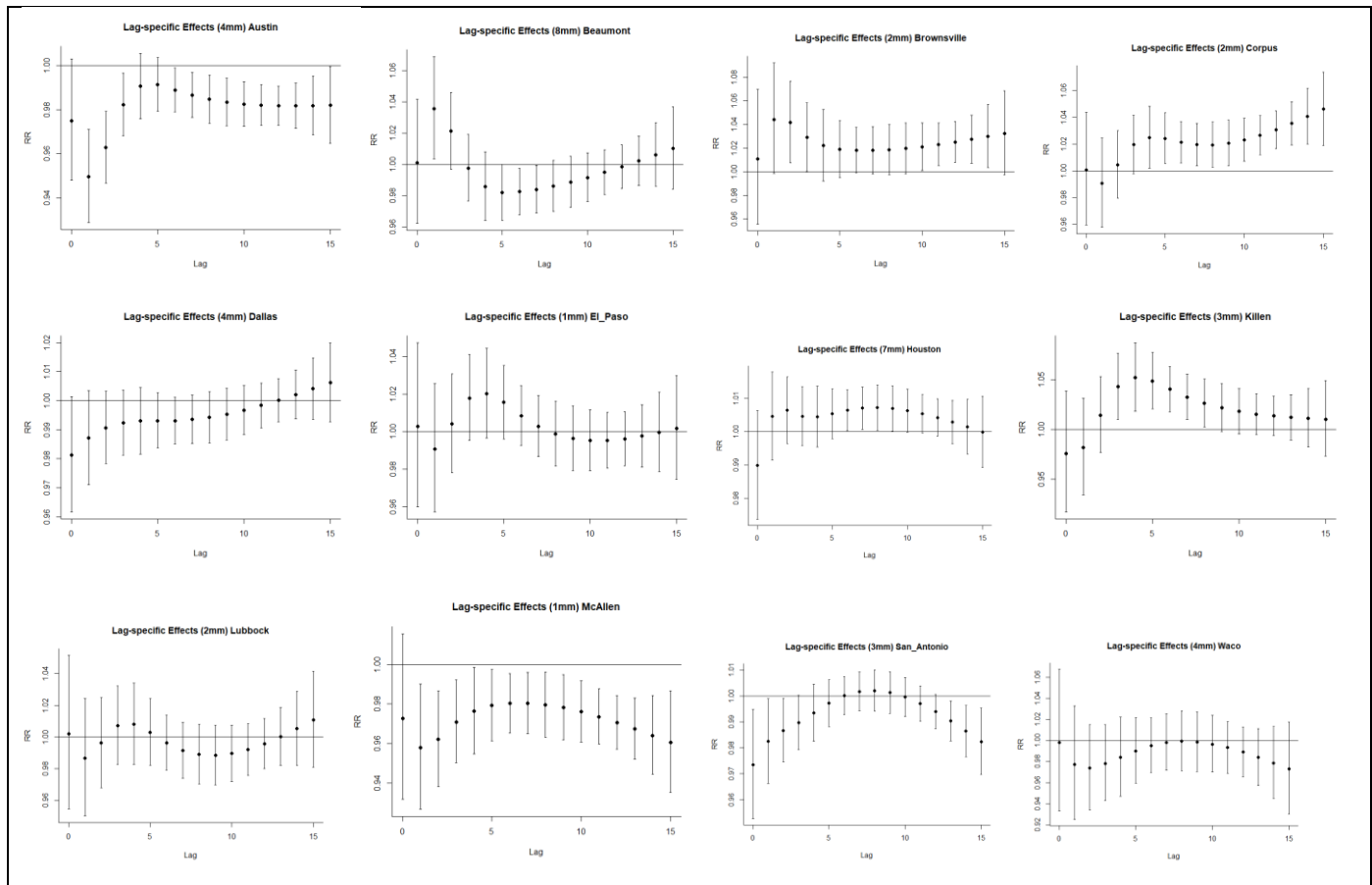


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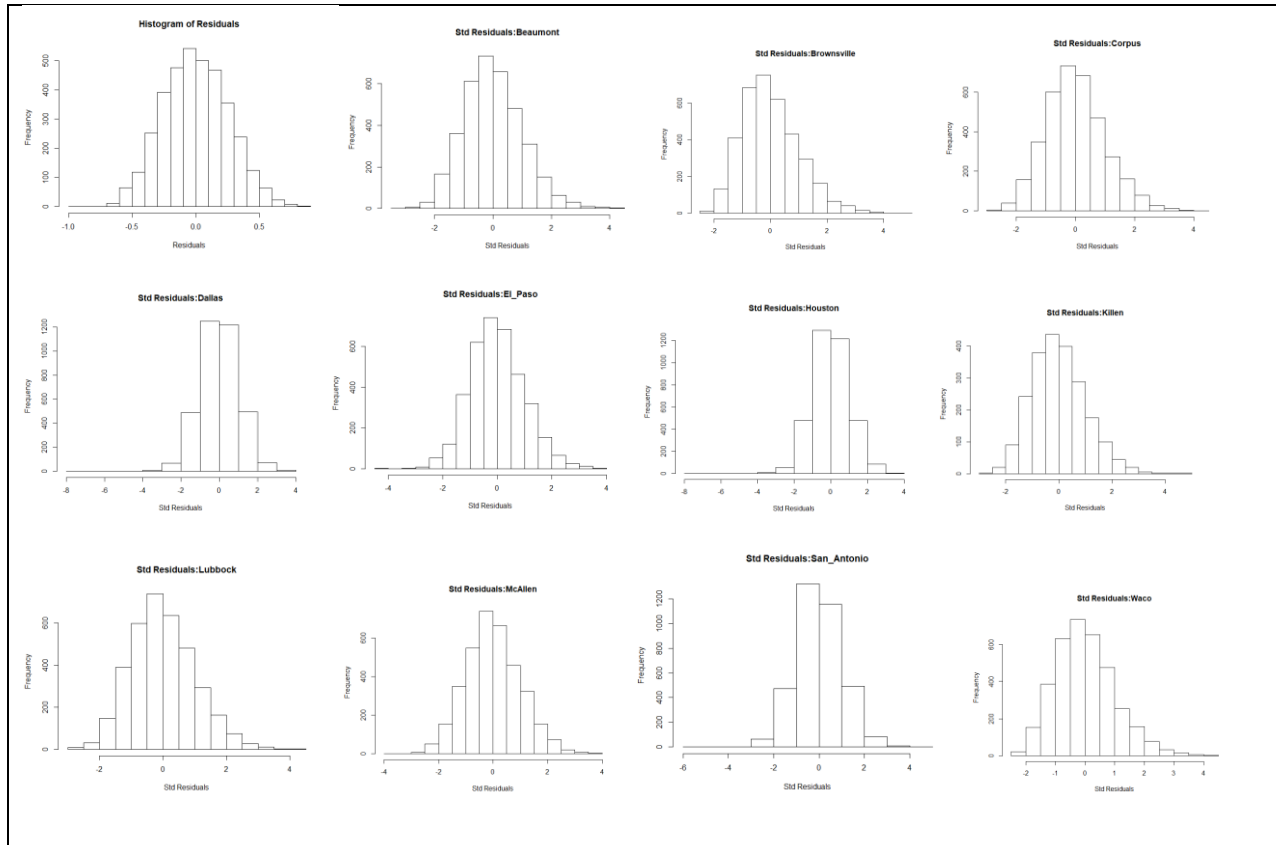


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